

Anatomy of Temporal bone

drtbalu

Surgeon's Perspective

The Squama (squama temporalis).—The squama forms the anterior and upper part of the bone, and is scale-like, thin, and translucent.

Surfaces. — Its outer surface (Fig. 1) is smooth and convex; it affords attachment to the Temporalis muscle, and forms part of the temporal fossa; on its hinder part is a vertical groove for the middle temporal artery. A curved line, the temporal line, or supramastoid crest, runs backward and upward across its posterior part; it serves for the attachment of the temporal fascia, and limits the origin of the Temporalis muscle. The boundary between the squama and the mastoid portion of the bone, as indicated by traces of the original suture, lies about 1 cm. below this line. Projecting from the lower part of the squama is a long, arched process, the zygomatic process. This process is at first directed lateralward, its two surfaces looking upward and downward; it then appears as if twisted inward upon itself, and runs forward, its surfaces now looking medialward and lateralward. The superior border is long, thin, and sharp, and serves for the attachment of the temporal fascia; the inferior, short, thick, and arched, has attached to it some fibers of the Masseter. The lateral

surface is convex and subcutaneous; the medial is concave, and affords attachment to the Masseter. The anterior end is deeply serrated and articulates with the zygomatic bone. The posterior end is connected to the squama by two roots, the anterior and posterior roots. The posterior root, a prolongation of the upper border, is strongly marked; it runs backward above the external acoustic meatus, and is continuous with the temporal line. The anterior root, continuous with the lower border, is short but broad and strong; it is directed medialward and ends in a rounded eminence, the articular tubercle (*eminencia articularis*). This tubercle forms the front boundary of the mandibular fossa, and in the fresh state is covered with cartilage. In front of the articular tubercle is a small triangular area which assists in forming the infratemporal fossa; this area is separated from the outer surface of the squama by a ridge which is continuous behind with the anterior root of the zygomatic process, and in front, in the articulated skull, with the infratemporal crest on the great wing of the sphenoid. Between the posterior wall of the external acoustic meatus and the posterior root of the zygomatic process is the area called the suprameatal triangle (Macewen), or mastoid fossa, through which an instrument may be pushed into the tympanic antrum. At the junction of the anterior root with the zygomatic process is a projection for the attachment of the temporomandibular ligament; and behind the anterior root is an oval depression, forming part of the mandibular fossa, for the reception of the condyle of the mandible. The mandibular fossa (glenoid fossa) is bounded, in front, by the articular tubercle; behind, by the tympanic part of the bone, which separates it from the external acoustic meatus; it is divided into two parts by a narrow slit, the petrotympanic fissure (Glaserian fissure). The anterior part, formed by the squama, is smooth, covered in the fresh state with cartilage, and articulates with the condyle of the mandible. Behind this part of the fossa is a small conical eminence; this is the representative of a prominent tubercle which, in some mammals, descends behind the condyle of the mandible, and prevents its backward displacement. The posterior part of the mandibular fossa, formed by the tympanic part of the bone, is non-articular, and sometimes lodges a portion of the parotid gland. The petrotympanic fissure leads into the middle ear or tympanic cavity; it lodges the anterior process of the malleus, and transmits the tympanic branch of the internal maxillary artery. The chorda tympani nerve passes through a canal (canal of Huguier), separated from the anterior edge of the petrotympanic fissure by a thin scale of bone and situated on the lateral side of the auditory tube, in the retiring angle between the squama and the petrous portion of the temporal.

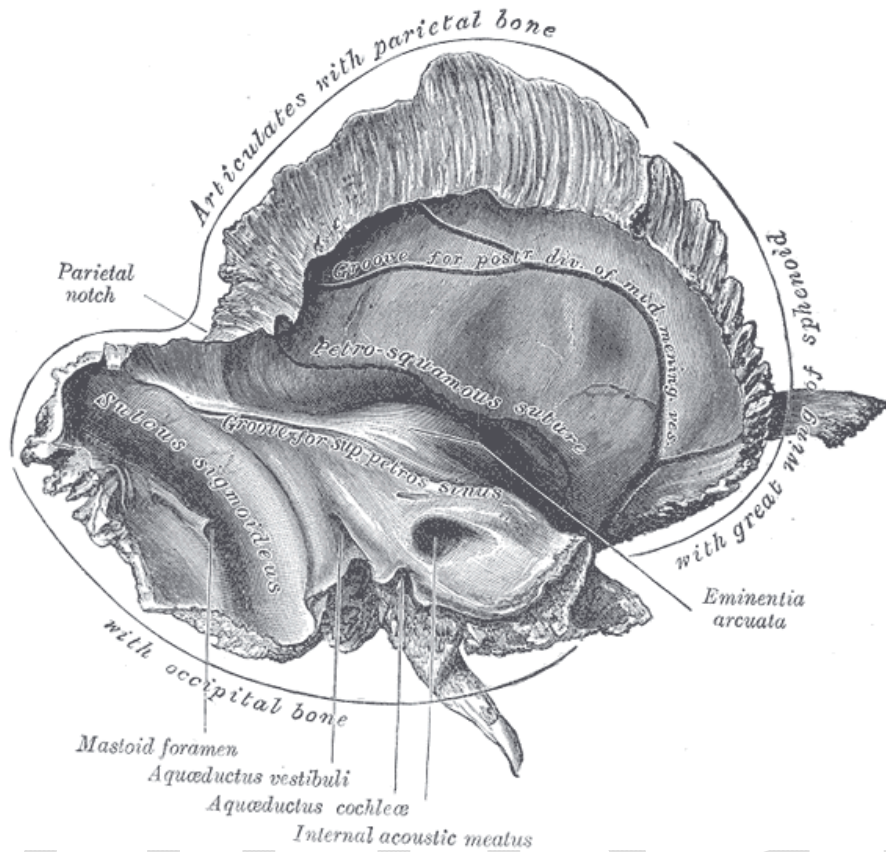


Fig 2. Left temporal bone inner surface

The internal surface of the squama (Fig. 2) is concave; it presents depressions corresponding to the convolutions of the temporal lobe of the brain, and grooves for the branches of the middle meningeal vessels.

Borders: — The superior border is thin, and bevelled at the expense of the internal table, so as to overlap the squamous border of the parietal bone, forming with it the squamosal suture. Posteriorly, the superior border forms an angle, the parietal notch, with the mastoid portion of the bone. The antero-inferior border is thick, serrated, and bevelled at the expense of the inner table above and of the outer below, for articulation with the great wing of the sphenoid.

Mastoid Portion (pars mastoidea). — The mastoid portion forms the posterior part of the bone.

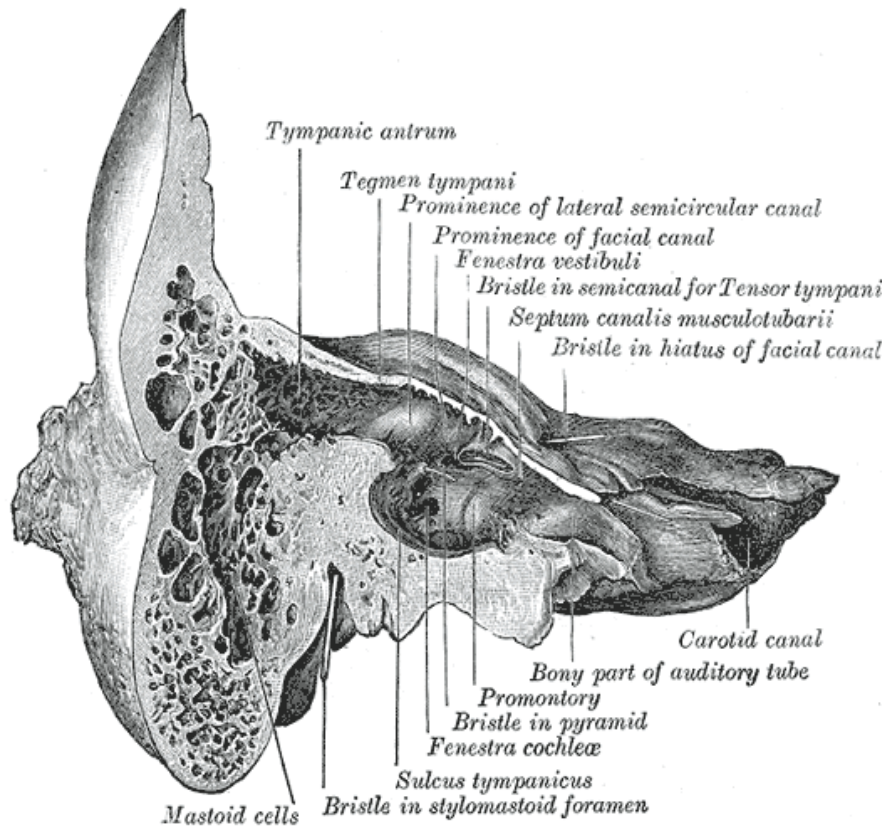


Fig 3 Coronal section of right temporal bone

Surfaces.— Its outer surface (Fig. 1) is rough, and gives attachment to the Occipitalis and Auricularis posterior. It is perforated by numerous foramina; one of these, of large size, situated near the posterior border, is termed the mastoid foramen; it transmits a vein to the transverse sinus and a small branch of the occipital artery to the dura mater. The position and size of this foramen are very variable; it is not always present; sometimes it is situated in the occipital bone, or in the suture between the temporal and the occipital. The mastoid portion is continued below into a conical projection, the mastoid process, the size and form of which very somewhat; it is larger in the male than in the female. This process serves for the attachment of the Sternocleidomastoideus, Splenius capitis, and Longissimus capitis. On the medial side of the process is a deep groove, the mastoid notch (digastric fossa), for the attachment of the Digastricus; medial to this is a shallow furrow, the occipital groove, which lodges the occipital artery.

The inner surface of the mastoid portion presents a deep, curved groove, the sigmoid sulcus, which lodges part of the transverse sinus; in it may be seen the opening of the mastoid foramen. The groove for the transverse sinus is separated from the innermost of the mastoid air cells by a very thin lamina of bone, and even this may be partly deficient.

Borders: The superior border of the mastoid portion is broad and serrated, for articulation with the mastoid angle of the parietal. The posterior border, also serrated, articulates with the inferior border of the occipital between the lateral angle and jugular process. Anteriorly the mastoid portion is fused with the descending process of the squama above; below it enters into the formation of the external acoustic meatus and the tympanic cavity.

A section of the mastoid process (Fig. 3) shows it to be hollowed out into a number of spaces, the mastoid cells, which exhibit the greatest possible variety as to their size and number. At the upper and front part of the process they are large and irregular and contain air, but toward the lower part they diminish in size, while those at the apex of the process are frequently quite small and contain marrow; occasionally they are entirely absent, and the mastoid is then solid throughout. In addition to these a large irregular cavity is situated at the upper and front part of the bone. It is called the tympanic antrum, and must be distinguished from the mastoid cells, though it communicates with them. Like the mastoid cells it is filled with air and lined by a prolongation of the mucous membrane of the tympanic cavity, with which it communicates. The tympanic antrum is bounded above by a thin plate of bone, the tegmen tympani, which separates it from the middle fossa of the base of the skull; below by the mastoid process; laterally by the squama just below the temporal line, and medially by the lateral semicircular canal of the internal ear which projects into its cavity. It opens in front into that portion of the tympanic cavity which is known as the attic or epitympanic recess. The tympanic antrum is a cavity of some considerable size at the time of birth; the mastoid air cells may be regarded as diverticula from the antrum, and begin to appear at or before birth; by the fifth year they are well-marked, but their development is not completed until toward puberty.

Petrous Portion (pars petrosa [pyramis]).—The petrous portion or pyramid is pyramidal and is wedged in at the base of the skull between the sphenoid and occipital. Directed medialward, forward, and a little upward, it presents for examination a base, an apex, three surfaces, and three angles, and contains, in its interior, the essential parts of the organ of hearing.

Base: The base is fused with the internal surfaces of the squama and mastoid portion.

Apex: The apex, rough and uneven, is received into the angular interval between the posterior border of the great wing of the sphenoid and the basilar part of the occipital; it presents the anterior or internal orifice of the carotid canal, and forms the postero-lateral boundary of the foramen lacerum.

Surfaces: The anterior surface forms the posterior part of the middle fossa of the base of the skull, and is continuous with the inner surface of the squamous portion, to which it is united by the petrosquamous suture, remains of which are distinct even at a late period of life. It is marked by depressions for the convolutions of the brain, and presents six points for examination: (1) near the center, an eminence (*eminencia arcuata*) which indicates the situation of the superior semicircular canal; (2) in front of and a little lateral to this eminence, a depression indicating the position of the tympanic cavity: here the layer of bone which separates the tympanic from the cranial cavity is extremely thin, and is known as the tegmen tympani; (3) a

shallow groove, sometimes double, leading lateralward and backward to an oblique opening, the hiatus of the facial canal, for the passage of the greater superficial petrosal nerve and the petrosal branch of the middle meningeal artery; (4) lateral to the hiatus, a smaller opening, occasionally seen, for the passage of the lesser superficial petrosal nerve; (5) near the apex of the bone, the termination of the carotid canal, the wall of which in this situation is deficient in front; (6) above this canal the shallow trigeminal impression for the reception of the semilunar ganglion.

The posterior surface (Fig. 2) forms the front part of the posterior fossa of the base of the skull, and is continuous with the inner surface of the mastoid portion. Near the center is a large orifice, the internal acoustic meatus, the size of which varies considerably; its margins are smooth and rounded, and it leads into a short canal, about 1 cm. in length, which runs lateralward. It transmits the facial and acoustic nerves and the internal auditory branch of the basilar artery. The lateral end of the canal is closed by a vertical plate, which is divided by a horizontal crest, the crista falciformis, into two unequal portions (Fig. 4). Each portion is further subdivided by a vertical ridge into an anterior and a posterior part. In the portion beneath the crista falciformis are three sets of foramina; one group, just below the posterior part of the crest, situated in the area cribrosa media, consists of several small openings for the nerves to the sacculæ; below and behind this area is the foramen singulare, or opening for the nerve to the posterior semicircular duct; in front of and below the first is the tractus spiralis foraminosus, consisting of a number of small spirally arranged openings, which encircle the canalis centralis cochleæ; these openings together with this central canal transmit the nerves to the cochlea. The portion above the crista falciformis presents behind, the area cribrosa superior, pierced by a series of small openings, for the passage of the nerves to the utricle and the superior and lateral semicircular ducts, and, in front, the area facians, with one large opening, the commencement of the canal for the facial nerve (aquæductus Fallopii). Behind the internal acoustic meatus is a small slit almost hidden by a thin plate of bone, leading to a canal, the aquæductus vestibuli, which transmits the ductus endolymphaticus together with a small artery and vein. Above and between these two openings is an irregular depression which lodges a process of the dura mater and transmits a small vein; in the infant this depression is represented by a large fossa, the subarcuate fossa, which extends backward as a blind tunnel under the superior semicircular canal.

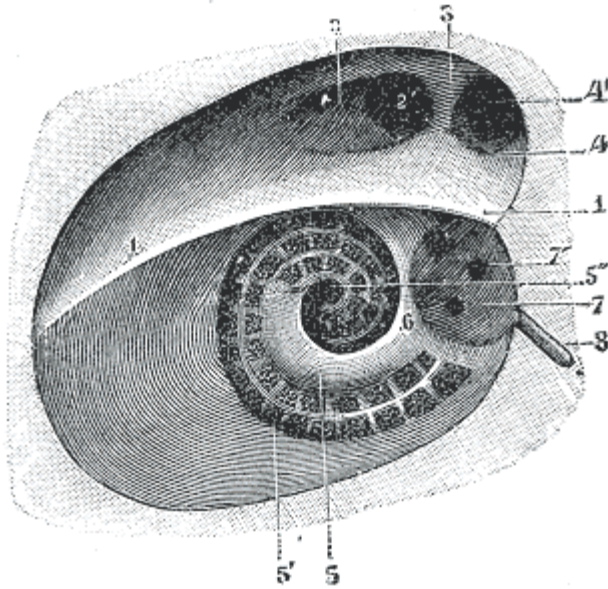


Fig 4 Diagrammatic view of the fundus of the right internal acoustic meatus.

1. Crista falciformis. 2. Area facialis, with (2') internal opening of the facial canal. 3. Ridge separating the area facialis from the area cribrosa superior. 4. Area cribrosa superior, with (4') openings for nerve filaments. 5. Anterior inferior cribriform area, with (5') the tractus spiralis foraminosus, and (5'') the canalis centralis of the cochlea. 6. Ridge separating the tractus spiralis foraminosus from the area cribrosa media. 7. Area cribrosa media, with (7') orifices for nerves to saccule. 8. Foramen singulare

The inferior surface (Fig. 5) is rough and irregular, and forms part of the exterior of the base of the skull. It presents eleven points for examination: (1) near the apex is a rough surface, quadrilateral in form, which serves partly for the attachment of the Levator veli palatini and the cartilaginous portion of the auditory tube, and partly for connection with the basilar part of the occipital bone through the intervention of some dense fibrous tissue; (2) behind this is the large circular aperture of the carotid canal, which ascends at first vertically, and then, making a bend, runs horizontally forward and medialward; it transmits into the cranium the internal carotid artery, and the carotid plexus of nerves; (3) medial to the opening for the carotid canal and close to its posterior border, in front of the jugular fossa, is a triangular depression; at the apex of this is a small opening, the aquæductus cochleæ, which lodges a tubular prolongation of the dura mater establishing a communication between the perilymphatic space and the subarachnoid space, and transmits a vein from the cochlea to join the internal jugular; (4) behind these openings is a deep depression, the jugular fossa, of variable depth and size in different skulls; it lodges the bulb of the internal jugular vein; (5) in the bony ridge dividing the carotid canal from the jugular fossa is the small inferior tympanic canaliculus for the passage of the tympanic branch of the glossopharyngeal nerve; (6) in the lateral part of the jugular fossa is the mastoid canaliculus for the entrance of the auricular branch of the vagus nerve; (7) behind the jugular fossa is a

quadrilateral area, the jugular surface, covered with cartilage in the fresh state, and articulating with the jugular process of the occipital bone; (8) extending backward from the carotid canal is the vaginal process, a sheath-like plate of bone, which divides behind into two laminæ; the lateral lamina is continuous with the tympanic part of the bone, the medial with the lateral margin of the jugular surface; (9) between these laminæ is the styloid process, a sharp spine, about 2.5 cm. in length; (10) between the styloid and mastoid processes is the stylomastoid foramen; it is the termination of the facial canal, and transmits the facial nerve and stylomastoid artery; (11) situated between the tympanic portion and the mastoid process is the tympanomastoid fissure, for the exit of the auricular branch of the vagus nerve.

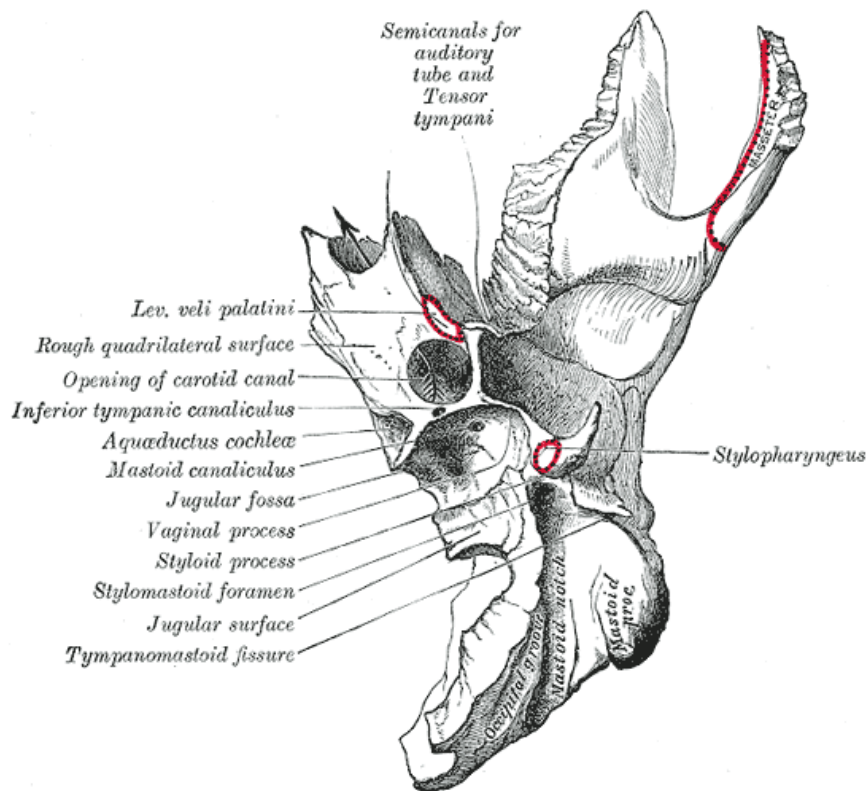


Fig 5 Left temporal bone inferior surface

Angles: The superior angle, the longest, is grooved for the superior petrosal sinus, and gives attachment to the tentorium cerebelli; at its medial extremity is a notch, in which the trigeminal nerve lies. The posterior angle is intermediate in length between the superior and the anterior. Its medial half is marked by a sulcus, which forms, with a corresponding sulcus on the occipital bone, the channel for the inferior petrosal sinus. Its lateral half presents an excavation—the jugular fossa—which, with the jugular notch on the occipital, forms the jugular foramen; an eminence occasionally projects from the center of the fossa, and divides the foramen into two. The anterior angle is divided into two parts—a lateral joined to the squama by a suture (petrosquamous), the remains of which are more or less distinct; a medial, free, which articulates with the spinous process of the sphenoid.

At the angle of junction of the petrous part and the squama are two canals, one above the other, and separated by a thin plate of bone, the septum canalis musculotubarii (processus cochleariformis); both canals lead into the tympanic cavity. The upper one (semicanalis m. tensoris tympani) transmits the Tensor tympani, the lower one (semicanalis tubæ auditivæ) forms the bony part of the auditory tube.

The tympanic cavity, auditory ossicles, and internal ear, are described with the organ of hearing.

Tympanic Part (pars tympanica): The tympanic part is a curved plate of bone lying below the squama and in front of the mastoid process.

Surfaces: Its postero-superior surface is concave, and forms the anterior wall, the floor, and part of the posterior wall of the bony external acoustic meatus. Medially, it presents a narrow furrow, the tympanic sulcus, for the attachment of the tympanic membrane. Its antero-inferior surface is quadrilateral and slightly concave; it constitutes the posterior boundary of the mandibular fossa, and is in contact with the retromandibular part of the parotid gland.

Borders: Its lateral border is free and rough, and gives attachment to the cartilaginous part of the external acoustic meatus. Internally, the tympanic part is fused with the petrous portion, and appears in the retreating angle between it and the squama, where it lies below and lateral to the orifice of the auditory tube. Posteriorly, it blends with the squama and mastoid part, and forms the anterior boundary of the tympanomastoid fissure. Its upper border fuses laterally with the back of the postglenoid process, while medially it bounds the petrotympanic fissure. The medial part of the lower border is thin and sharp; its lateral part splits to enclose the root of the styloid process, and is therefore named the vaginal process. The central portion of the tympanic part is thin, and in a considerable percentage of skulls is perforated by a hole, the foramen of Huschke.

The external acoustic meatus is nearly 2 cm. long and is directed inward and slightly forward: at the same time it forms a slight curve, so that the floor of the canal is convex upward. In sagittal section it presents an oval or elliptical shape with the long axis directed downward and slightly backward. Its anterior wall and floor and the lower part of its posterior wall are formed by the tympanic part; the roof and upper part of the posterior wall by the squama. Its inner end is closed, in the recent state, by the tympanic membrane; the upper limit of its outer orifice is formed by the posterior root of the zygomatic process, immediately below which there is sometimes seen a small spine, the suprameatal spine, situated at the upper and posterior part of the orifice.

Styloid Process (processus styloideus): The styloid process is slender, pointed, and of varying length; it projects downward and forward, from the under surface of the temporal bone. Its proximal part (tympanohyal) is ensheathed by the vaginal process of the tympanic portion, while its distal part (stylohyal) gives attachment to the stylohyoid and stylomandibular ligaments, and to the Styloglossus, Stylohyoideus, and Stylopharyngeus muscles. The stylohyoid ligament extends from the apex of the process to the lesser cornu of the hyoid bone, and in some instances is partially, in others completely, ossified.

Structure: The structure of the squama is like that of the other cranial bones: the mastoid portion is spongy, and the petrous portion dense and hard.

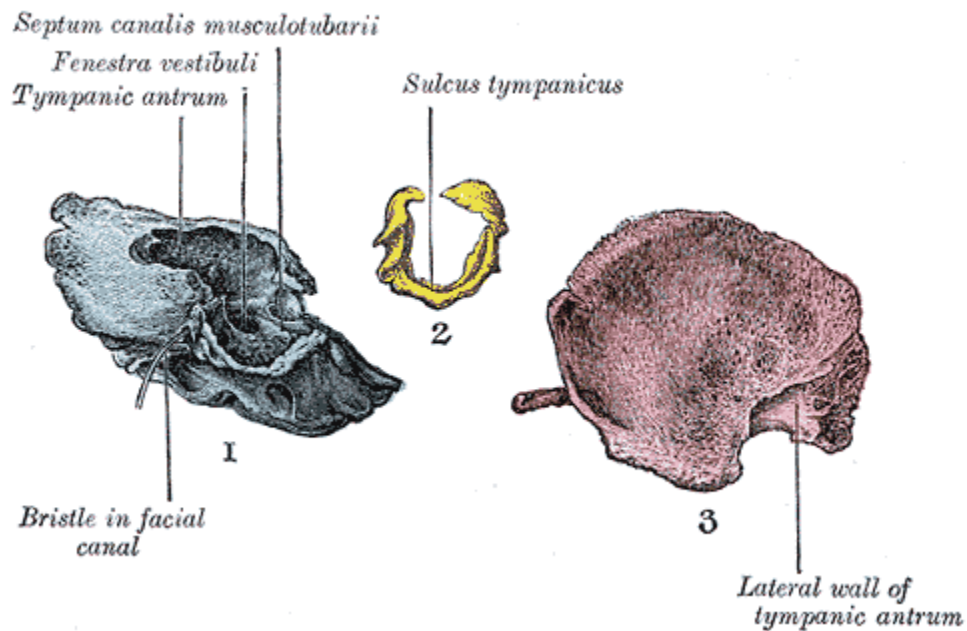


Fig 6 The three principal parts of the temporal bone at birth. 1. Outer surface of petromastoid part. 2. Outer surface of tympanic ring. 3. Inner surface of squama

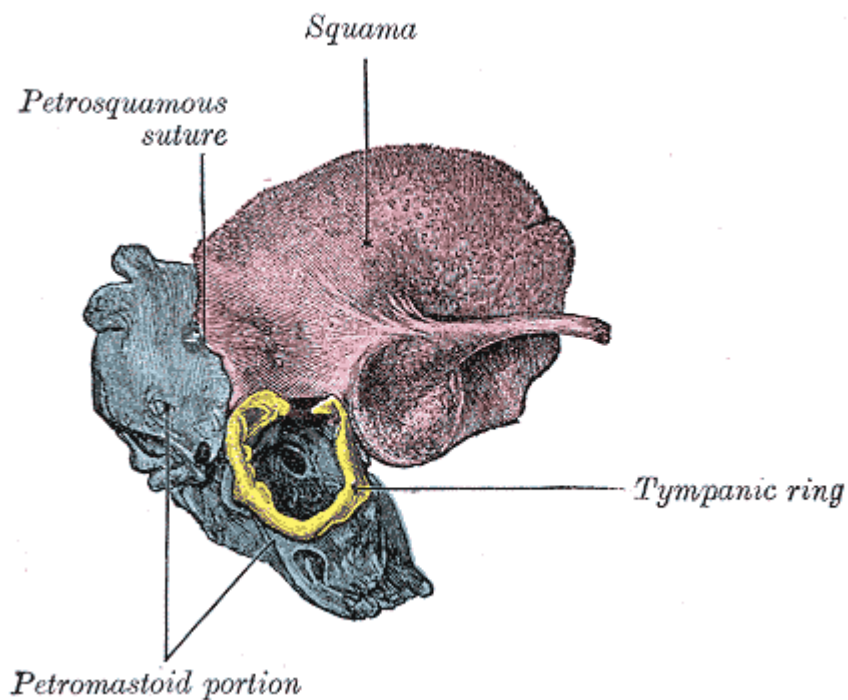


Fig 7 Temporal bone at birth. Outer aspect.

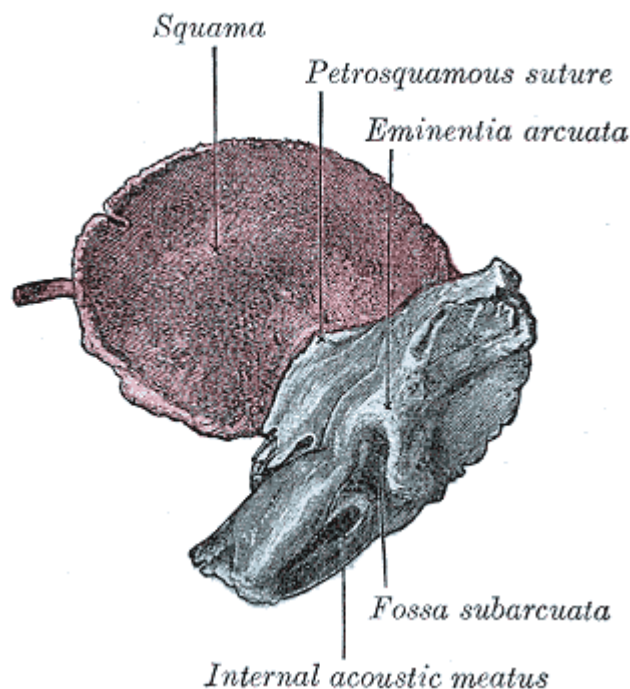


Fig 8 Temporal bone at birth. Inner aspect

Ossification.—The temporal bone is ossified from eight centers, exclusive of those for the internal ear and the tympanic ossicles, viz., one for the squama including the zygomatic process, one for the tympanic part, four for the petrous and mastoid parts, and two for the styloid process. Just before the close of fetal life (Fig. 7) the temporal bone consists of three principal parts: 1. The squama is ossified in membrane from a single nucleus, which appears near the root of the zygomatic process about the second month. 2. The petromastoid part is developed from four centers, which make their appearance in the cartilaginous ear capsule about the fifth or sixth month. One appears in the neighborhood of the eminentia arcuata, spreads in front and above the internal acoustic meatus and extends to the apex of the bone; it forms part of the cochlea, vestibule, superior semicircular canal, and medial wall of the tympanic cavity. A second (opisthotic) appears at the promontory on the medial wall of the tympanic cavity and surrounds the fenestra cochleæ; it forms the floor of the tympanic cavity and vestibule, surrounds the carotid canal, invests the lateral and lower part of the cochlea, and spreads medially below the internal acoustic meatus. A third (ptertotic) roofs in the tympanic cavity and antrum; while the fourth (epiotic) appears near the posterior semicircular canal and extends to form the mastoid process. 3. The tympanic ring is an incomplete circle, in the concavity of which is a groove, the tympanic sulcus, for the attachment of the circumference of the tympanic membrane. This ring expands to form the tympanic

part, and is ossified in membrane from a single center which appears about the third month. The styloid process is developed from the proximal part of the cartilage of the second branchial or hyoid arch by two centers: one for the proximal part, the tympanohyal, appears before birth; the other, comprising the rest of the process, is named the stylohyal, and does not appear until after birth. The tympanic ring unites with the squama shortly before birth; the petromastoid part and squama join during the first year, and the tympanohyal portion of the styloid process about the same time (Figs. 6, 7). The stylohyal does not unite with the rest of the bone until after puberty and in some skulls never at all.

The chief subsequent changes in the temporal bone apart from increase in size are: (1) The tympanic ring extends outward and backward to form the tympanic part. This extension does not, however, take place at an equal rate all around the circumference of the ring, but occurs most rapidly on its anterior and posterior portions, and these outgrowths meet and blend, and thus, for a time, there exists in the floor of the meatus a foramen, the foramen of Huschke; this foramen is usually closed about the fifth year, but may persist throughout life. (2) The mandibular fossa is at first extremely shallow, and looks lateralward as well as downward; it becomes deeper and is ultimately directed downward. Its change in direction is accounted for as follows. The part of the squama which forms the fossa lies at first below the level of the zygomatic process. As, however, the base of the skull increases in width, this lower part of the squama is directed horizontally inward to contribute to the middle fossa of the skull, and its surfaces therefore come to look upward and downward; the attached portion of the zygomatic process also becomes everted, and projects like a shelf at right angles to the squama. (3) The mastoid portion is at first quite flat, and the stylomastoid foramen and rudimentary styloid process lie immediately behind the tympanic ring. With the development of the air cells the outer part of the mastoid portion grows downward and forward to form the mastoid process, and the styloid process and stylomastoid foramen now come to lie on the under surface. The descent of the foramen is necessarily accompanied by a corresponding lengthening of the facial canal. (4) The downward and forward growth of the mastoid process also pushes forward the tympanic part, so that the portion of it which formed the original floor of the meatus and contained the foramen of Huschke is ultimately found in the anterior wall. (5) The fossa subarcuata becomes filled up and almost obliterated.

Articulations: The temporal articulates with five bones: occipital, parietal, sphenoid, mandible and zygomatic.

Surgical anatomy

The extra cranial surface of the Temporal bone:

After exposure of the mastoid process using the retroauricular approach or the endaural approach, the supra meatal spine (Henle's spine), situated posterosuperiorly at the entrance of the ear canal has to be located. The shape and position of the suprameatal spine varies. 4 variants of the suprameatal spine have been described.

Variant 1: The suprameatal spine is small and smoothly contoured. In these cases, the tympanic bone, forming the anterior wall of the external acoustic meatus, is a vertical plate, and the styloid process is very short. A straight external acoustic meatus provides the best visualisation of the drum and tympanic cavity, and is the most favorable shape for tympanoplasty. (Fig S1)



Fig S1 Surgeon's view - The suprameatal spine (SS) is small. The tympanosquamous suture (TS) is not prominent, and the anterior part of the tympanic bone is a vertical plate, allowing a relatively wide ear canal. The styloid process (SP) is very short. The course of the tympanomastoid suture posteriorly in the ear canal and the tympanosquamous suture superiorly (TS) is shown. Mastoid foramen (MS) and cribriform area (arrow) is also shown.

Variant 2: The suprameatal spine is sharp and elongated. The deep tympanosquamous suture deludes a prominent anterior part of the tympanic bone, but the bone is thin and straight plate that provides good access to the middle ear. The skin is difficult to elevate from the deep suture, and the bone itself is not prominent. The styloid process is short. (Fig S2)

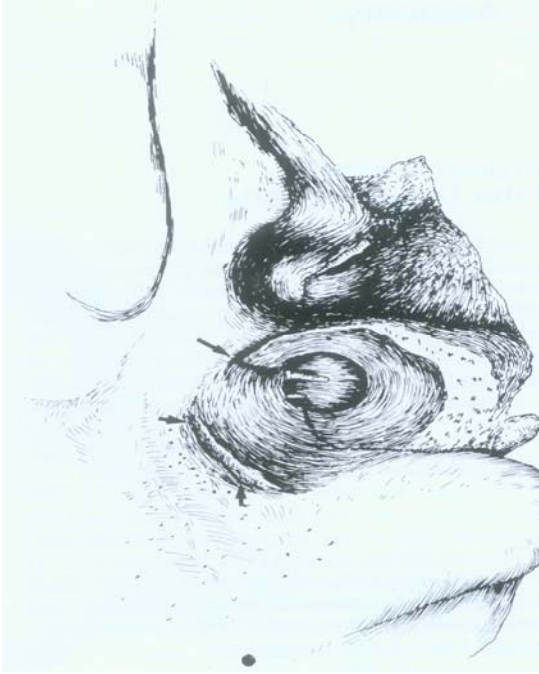


Fig S2 - The suprameatal spine is sharp and elongated crest (small arrows). The tympanosquamous suture is deep (large arrow), but the anterior part of the tympanic bone is a thin, straight plate, allowing good visualisation of the tympanomeatal angle. The styloid process is short.

Variant 3: The aperture for vessels lies somewhat superoposteriorly, close to the temporal line, and there is no true suprameatal crest, only a cone shaped depression. The styloid process is relatively long. The anterior part of the tympanic bone is thick and prominent. (Fig S3)

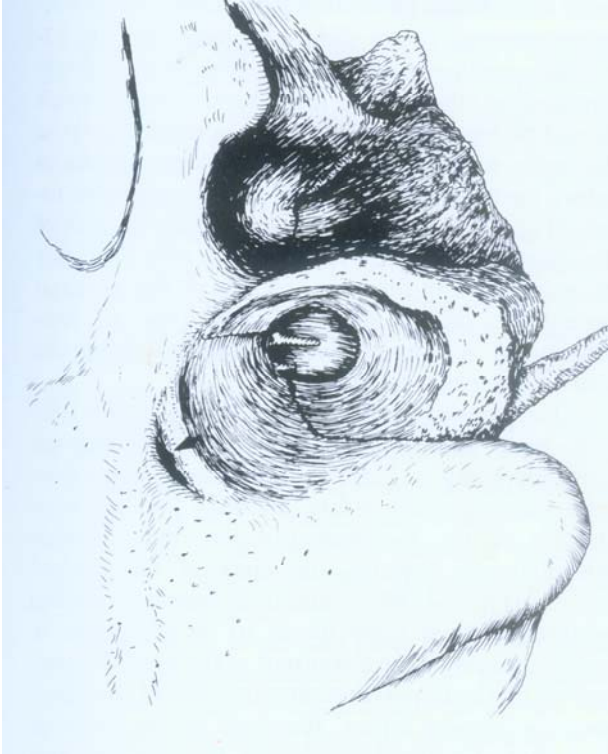


Fig S3 - There is no true suprameatal crest, only a cone shaped depression close to the temporal line (arrow). The styloid process is long and the tympanic bone is thick and prominent.

Variant 4: The suprameatal area is smooth, and there is no suprameatal crest. The external auditory meatus is oval in outline, and the tympanic part of the temporal bone, forming the anterior wall of the ear canal is prominent. The styloid process is very long. (Fig S4)



Fig S4 The suprameatal spine is not present. The anterior part of the tympanic bone is very prominent and thick (arrow), the ear canal is oval, the tympanosquamous suture is deep and the styloid process is long.

The temporal line is a horizontal ridge, continuing from the superior border of the zygomatic process posteriorly onto the mastoid cortex. This line approximately indicates the level of the middle cranial fossa dura. It is not always evident, sometimes it is a prominent sharp ridge, sometimes a broad prominence and in some other cases hardly recognizable. It is safest to start drilling the mastoid cortex a few millimeters below the temporal line and gradually proceed towards it.

Posterior to the suprameatal spine, a group of small holes in the mastoid cortex are occasionally seen, described as the cribriform area. Small vessels pass through these foramina to the mucosa of the underlying antrum in infants, and it is here that a Subperiosteal abscess forms in cases of acute coalescent mastoiditis. The cribriform area lies within Macewen's triangle an imaginary triangle defined by three lines. The first is the temporal line, the second is formed by the superior and posterior margins of the external bony meatus (this line goes through the suprameatal spine). The triangle is completed by a line drawn perpendicular to the first line and tangential to the second. This triangle roughly defines the mastoid antrum deep to the cortex. (Fig S5)

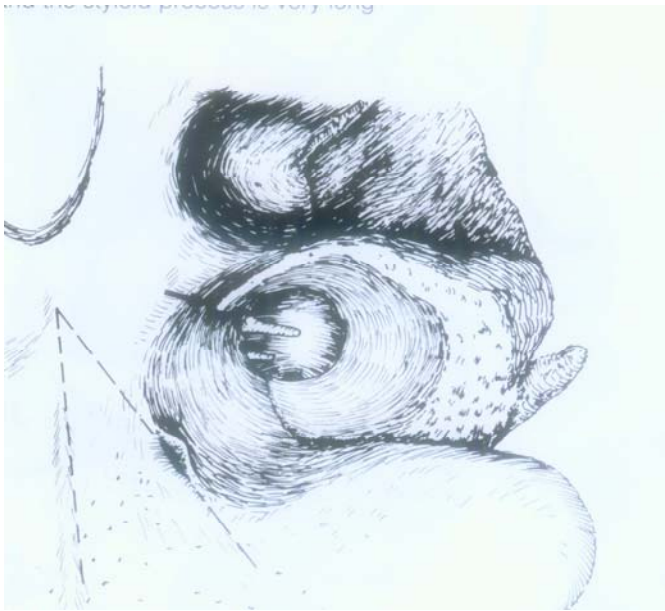


Fig S5 The temporal line is a sharp ridge and Macewen's triangle is indicated (dashed line).

Posteriorly, alongside the occipitomastoid suture, the mastoid foramen is visible, and this is the opening of the emissarium occipitale (santorini) (the occipital emissary vein) connecting the veins of the occipital region with the sigmoid sinus.

The roof of the bony ear canal is an important landmark, and should be visualized in any type of Mastoidectomy except simple Mastoidectomy. The canal skin should be carefully elevated, and the tympanosquamous suture should be located at the 12-o'clock position and exposed. The skin is firmly attached at the suture by fibrous tissue, which can be cut with a sickle knife in order to expose the entire suture. The size of the suture varies from a small, barely recognizable fissure to a deep notch, hampering the view of the Shrapnell's membrane region. Any irregular bone in the superior part of the ear canal should be drilled away in any type of Mastoidectomy.

The floor of the ear canal is formed by the tympanic bone, and should also be visualized before Mastoidectomy, at least as far as the tympanomastoid suture, which starts medially at the bony annulus at the 9-o'clock position and continues inferolaterally towards the apex of the mastoid. Removal of the tympanic bone between the two sutures gives an excellent view of the entire hypotympanum.

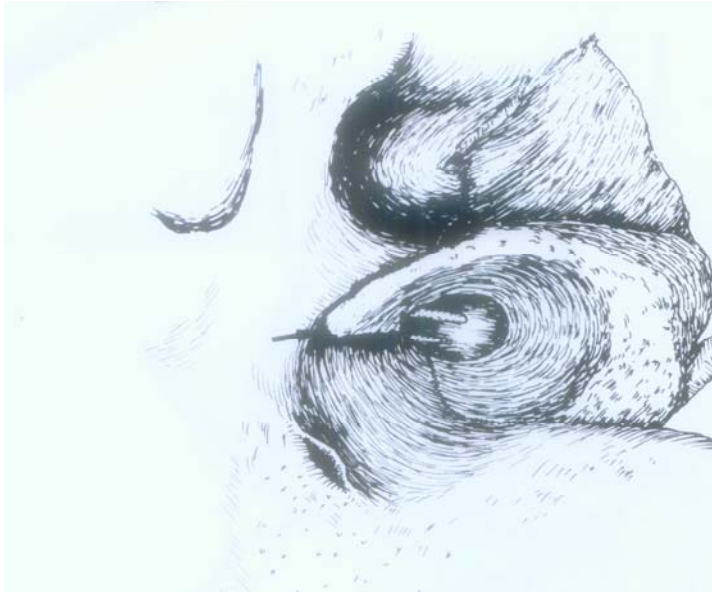


Fig S6 Bony ear canal with a deep tympanosquamous suture (arrow) and a prominent notch on the anterior part of the tympanic bone.



Fig S7 The tympanic bone has been removed to illustrate anatomic relationships in the hypotympanum P - promontory, with oval window superiorly, the round window niche posteriorly and the hypotympanic cells inferiorly. JB - jugular fossa; the entrance of the carotid artery and its course are shown (dashed lines).

The anatomy of the lateral part of the mastoid process varies widely in relation to the pneumatization, which can be almost non-existent or extensive with full pneumatization. Towards the tip of the mastoid process the cells are usually larger.

Middle cranial fossa dural plate:

Superiorly, the middle cranial fossa dura plate has to be located. This is achieved by drilling superiorly in the mastoid process, towards the temporal line. The mastoid air cells superiorly lie just under the cortical bone, and end in a solid bony plate. This plate continues medially. When the bone at the middle cranial fossa dural plate is thinned, the dura becomes visible, initially pinkish due to the vascularity followed by the whitish color.

Laterally, the middle fossa dura plate is large. It extends from the zygomatic region anteriorly to the sinodural angle and the superior petrosal sinus posteriorly. Because the superior petrosal sinus runs in an anteromedial direction, the area of the middle fossa dura plate diminishes medially towards the labyrinth.

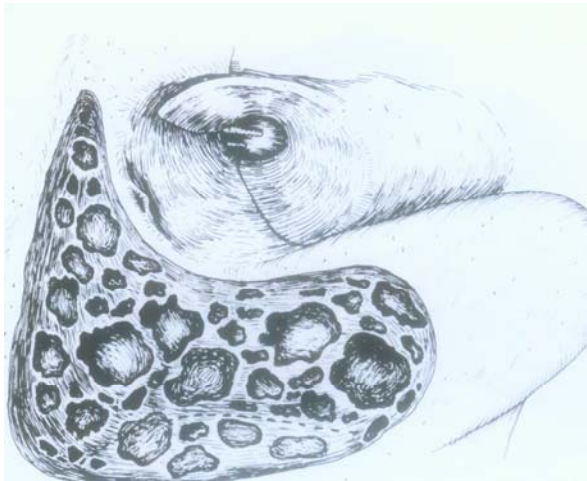


Fig S8 The subcortical lateral region of the mastoid process in a case of extensive pneumatization with large and small air cells occupying the subcortical space of the entire mastoid process. The cortical bone is relatively thin. Superiorly, the middle fossa dura plate is indicated, and posteriorly, the approximate position of the lateral sinus is indicated by dashed line.

The middle fossa dura plate is the roof, or tegmen, of the pneumatized spaces of the temporal bone. The tegmen is divided into the tegmen mastoidei, the most lateral part; the tegmen antri at the level of the mastoid antrum; and the tegmen tympani at the level of epitympanum, extending medially as far as the superior semicircular canal and the epitympanic recess anteriorly. (Fig S9)

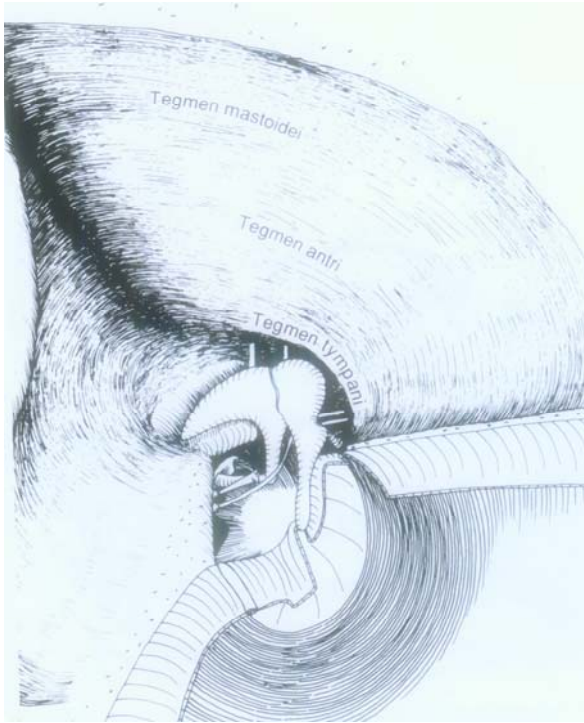


Fig S10 Division of the middle fossa dura into the tegmen mastoidei, tegmen antri, and the tegmen tympani in a large canal wall down Mastoidectomy.

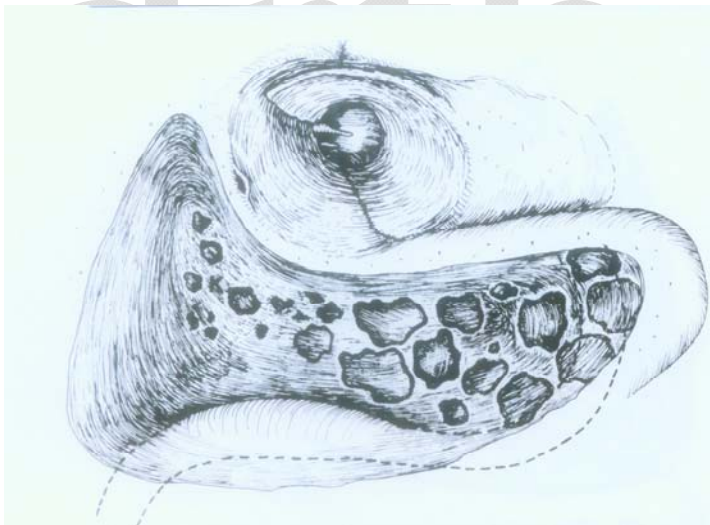


Fig S11 Cortical Mastoidectomy with exenteration of the lateral mastoid air cells. There are large mastoid air cells at the tip of the mastoid process, lateral to the sigmoid sinus. Superiorly the mastoid cells are removed until Korner's septum (K) is reached and the middle fossa dura plate is exposed. Posteriorly, the most lateral part of the sigmoid sinus is exposed, and its further course towards the mastoid tip under the facial nerve is indicated.

Sigmoid sinus:

The posterior limit of the standard mastoid cavity is the sigmoid sinus, or the lateral sinus. It is a continuation of the transverse sinus, and passes through the deep part of the mastoid process, under the facial nerve, toward the jugular bulb. In a well pneumatized mastoid process, the lateral aspect of the sigmoid sinus is

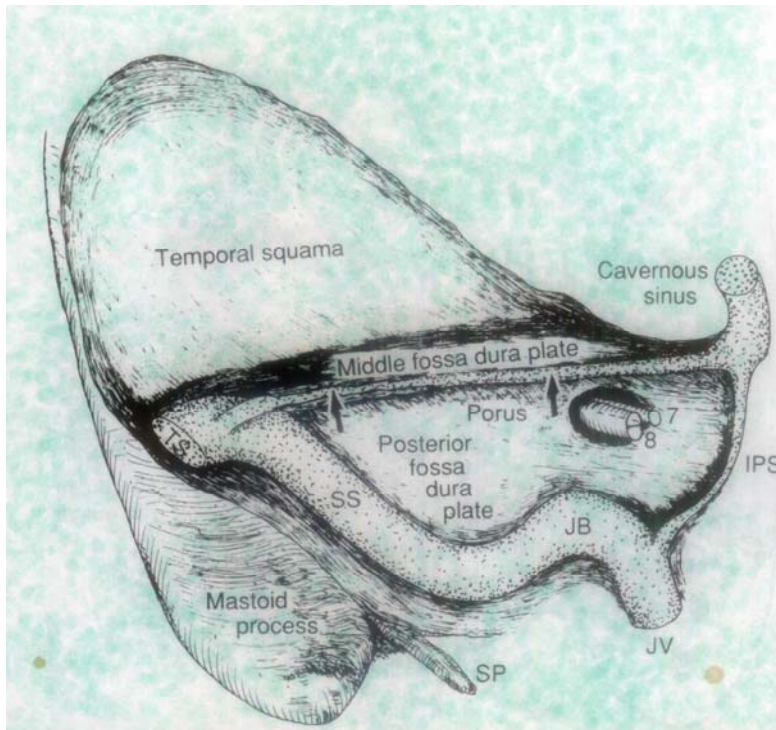
covered by the mastoid air cells. After removal of these cells, a slightly bluish discoloration of a smooth bony plate can be seen. With further thinning of the bone over the sinus, it becomes increasingly blue. The posterosuperior part of the sigmoid sinus is at the most superficial level. Inferiorly, the sinus lies gradually deeper, making an anterior curve and crossing the tip of the mastoid process at the level deep to the digastric crest. Adjacent to the vertical portion of the facial nerve before forming the jugular bulb, the sigmoid sinus lies the deepest.

The anatomy of the sigmoid sinus varies; it can be positioned anteriorly or posteriorly. It is more commonly anterior in poorly pneumatized bones.

Sinodural angle:

Is the angle between the middle fossa and posterior fossa dural plates and the superior part of the sigmoid sinus. In a well pneumatized ear, small air cells usually occupy the sinodural angle, and should be removed or opened in a mastoidectomy. Sometimes it is necessary to drill deep down into the angle, exposing the superior petrosal sinus. Laterally in this angle within the mastoid cortex, the emissarium mastoidium (citelli) is located. This emissary vein connects the sigmoid sinus with the veins draining the middle fossa dura and the temporal squama. The veins may lead to troublesome venous bleeding during the drilling of the cortical bone in the most lateral part of the sinodural angle. The sinodural angle is usually deep. In the depths of the angle, the superior petrosal sinus is located.

Fig S12 Showing inner surface of temporal bone – Superior petrosal sinus is indicated by arrows, IPS is inferior petrosal sinus, SS is sigmoid sinus TS is transverse sinus.



The superior petrosal sinus enters the sigmoid sinus on its medial surface, and runs in a bony sulcus along the edge of pars petrosal, dividing the middle fossa dura plate from the posterior fossa dura plate. It runs medially towards the petrous apex.

Korner's septum:

After exenteration of the superficial mastoid air cells, a thin bony plate can sometimes be seen at the bottom of the kidney shaped cavity. This plate is korner's septum, or petrosquamous lamina. In a well pneumatized mastoid process, the plate of Korner's septum is hardly recognizable. It is indicated by somewhat smaller cells in the upper part of the cavity. Korner's septum represents the site of embryonic fusion of the squamous and petrous portions of the temporal bone. Between the two components there is a suture line that is normally obliterated.

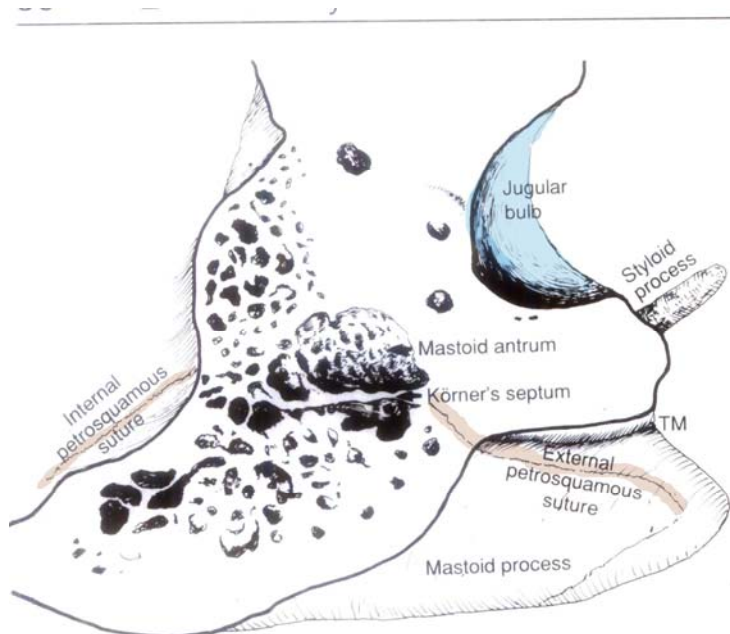


Fig S13 : showing korner's septum continuing superiorly into the internal petrosquamous suture line and inferiorly into the external petrosquamous suture, dividing the superficial lateral mastoid cells for these structures into squamomastoid cells and petromastoid cells lying medially to the sutures.

The presence of korner's septum may give a false impression of having reached the antrum. When this bony septum is present it divides the mastoid process into a superficial squamous portion and a deep petrosal portion, both portions open separately into the antrum.

If the squamous portion is poorly pneumatized or sclerotic, there may be great difficulty finding the mastoid antrum, unless one is aware about the presence of korner's septum and its penetration is a must to reach the air cells in the deep portion of the temporal bone.

The presence of korner's septum must be contemplated if there is difficulty in approaching the antrum or if the antrum is small or constricted, or if it is felt that the antrum has an anomalous position.

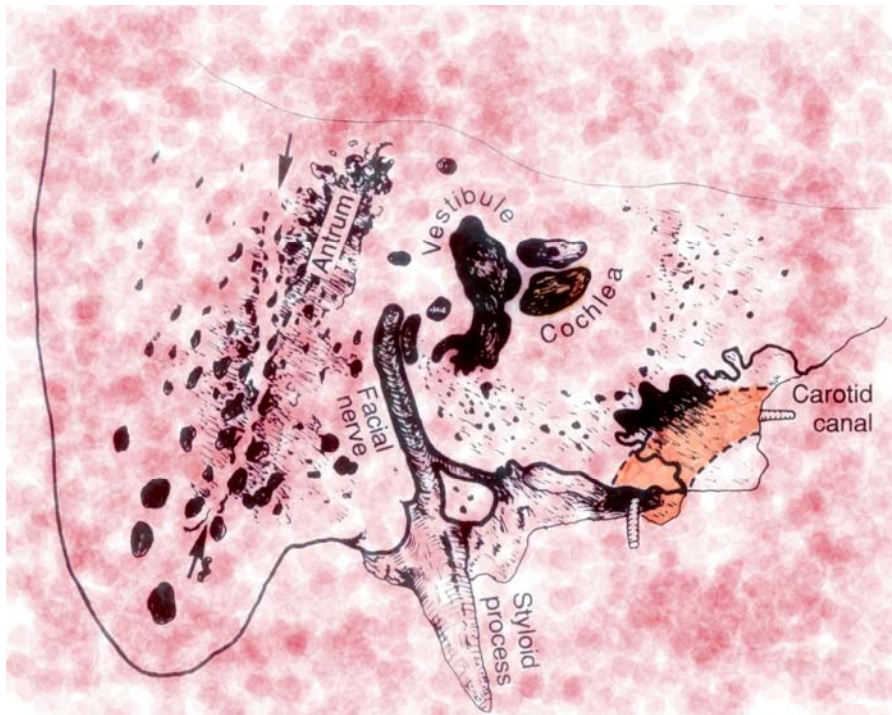


Fig S14: Korner's septum (arrows) with the antrum and petromastoid cells medial to it and the squamomastoid cells lateral to it.

Whenever a persistent and dense korner's septum is found, it should be removed to eliminate a dual pneumatic system. Failure to recognize the presence of korner's septum may lead a surgeon to seek the antrum at a more superficial level. During the procedure, the surgeon may wrongly search for the antrum anteroinferiorly, and may expose and damage the facial nerve. In such cases, drilling along the middle fossa dura plate is therefore extremely important until the antrum and lateral semicircular canal are located.

Mastoid antrum:

The antrum varies considerably in size; in a small sclerotic mastoid there is little or no pneumatization, the antrum is quite small. In ears with extensive pneumatization, it can be large. In ears with no petrosquamous lamina, there is no border between the large mastoid cells and the antrum. In such cases the antrum is large. Anterosuperiorly, the antrum continues along the tegmen to a narrow passage, the aditus ad antrum to the epitympanum.

The superior wall of the antrum is the tegmen antri. The medial wall of the antrum cavity is the labyrinth. Anteriorly, the lateral canal is immediately recognizable, and lateral to the canal, the incus body and short process of the incus are seen. The bone surrounding the antrum may be sclerotic, pneumatized with small air cells, or spongiotic in children.

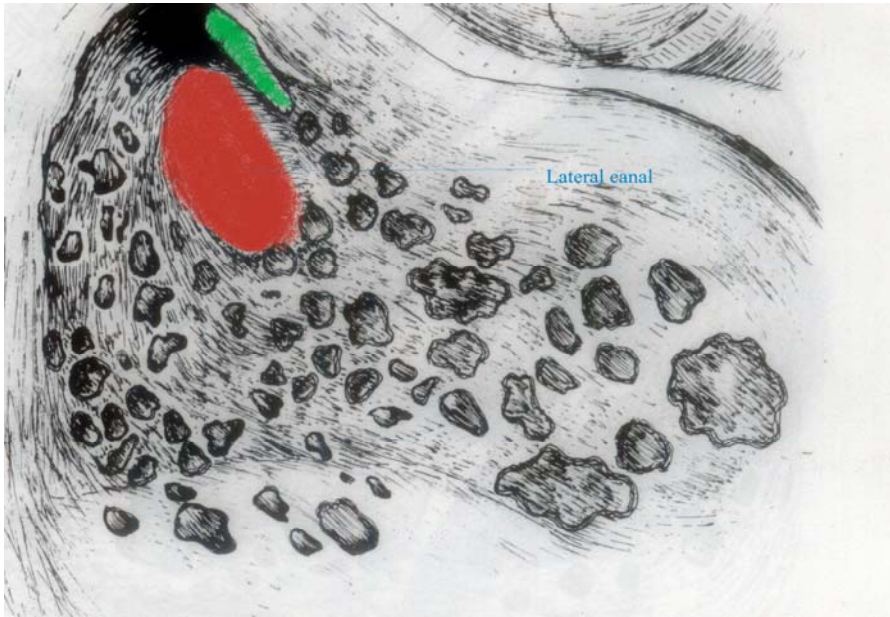


FIG S 15: Anteriorly one can see malleus and incus and medially the lateral canal.

The Labyrinth:

When the labyrinth is entered, the prominence of the lateral canal becomes visible and this is the most important landmark in the antrum. After removal of air cells the superior and posterior canals also become visible. The superior canal runs perpendicular to the lateral canal but is about 2 mm deeper. The anterior junction of the superior and lateral canals is at the anterior ampulla. The anterior crus then runs superiorly toward the tegmen tympani, and curves posteriorly to join with the posterior semicircular canal at the common crus. The posterior canal also runs perpendicular to the lateral canal. The posterior half of the posterior canal is located posterior to a line bisecting the lateral canal (Donaldson's line). The anterior half of the posterior canal runs anteriorly to the Donaldson's line and emerge deep to the facial nerve, to enter the vestibule.

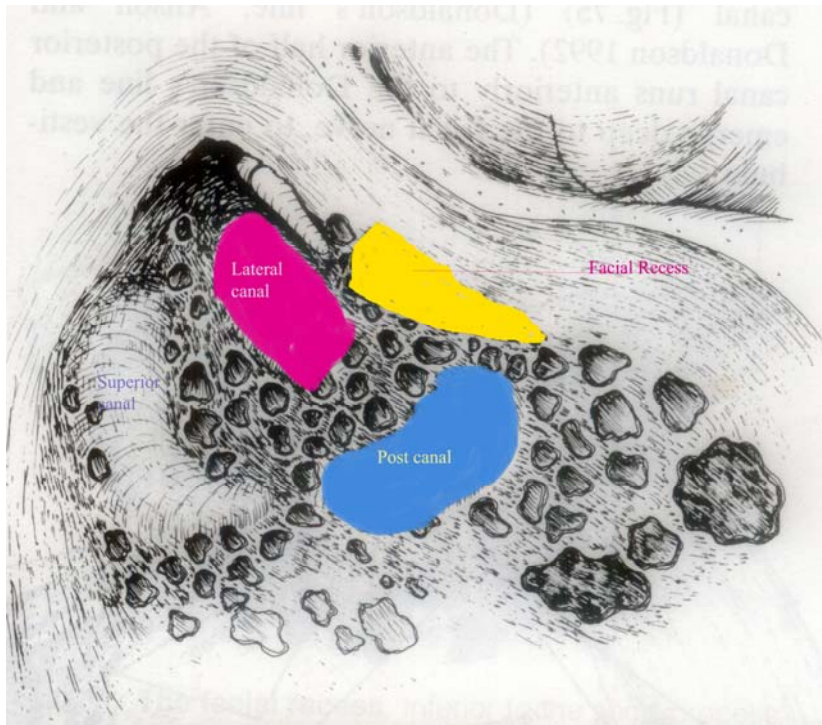


Fig S16 The three semicircular canals and facial recess demonstrated.

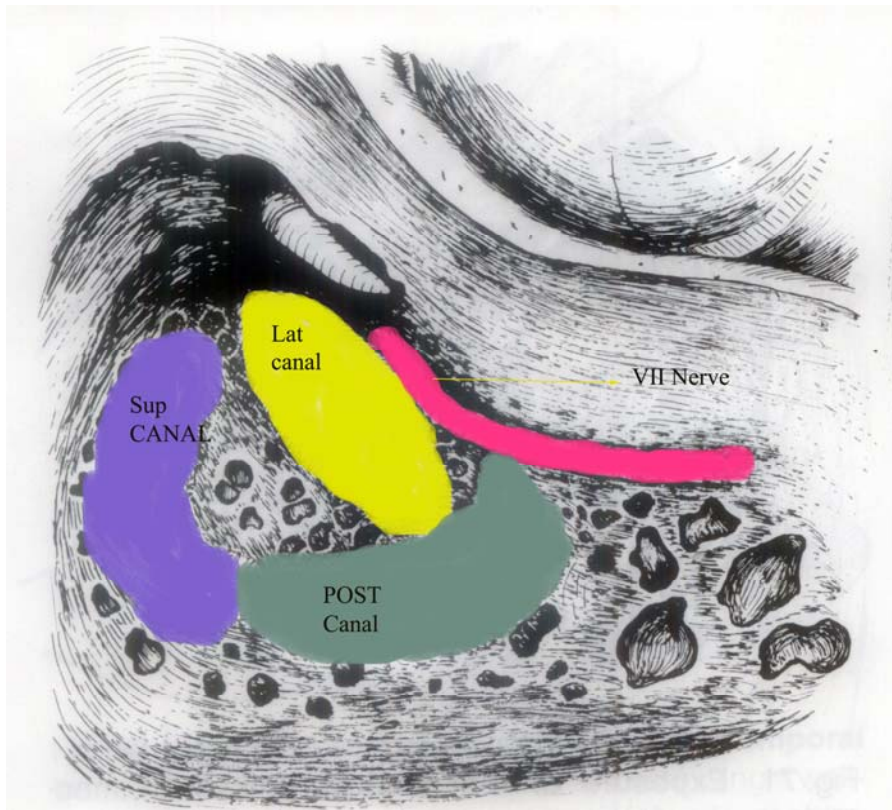


Fig S17 The supralabyrinthine, infralabyrinthine, and retro labyrinthine air cells are opened, the three semicircular canals are clearly seen, Facial nerve is also seen anteriorly.

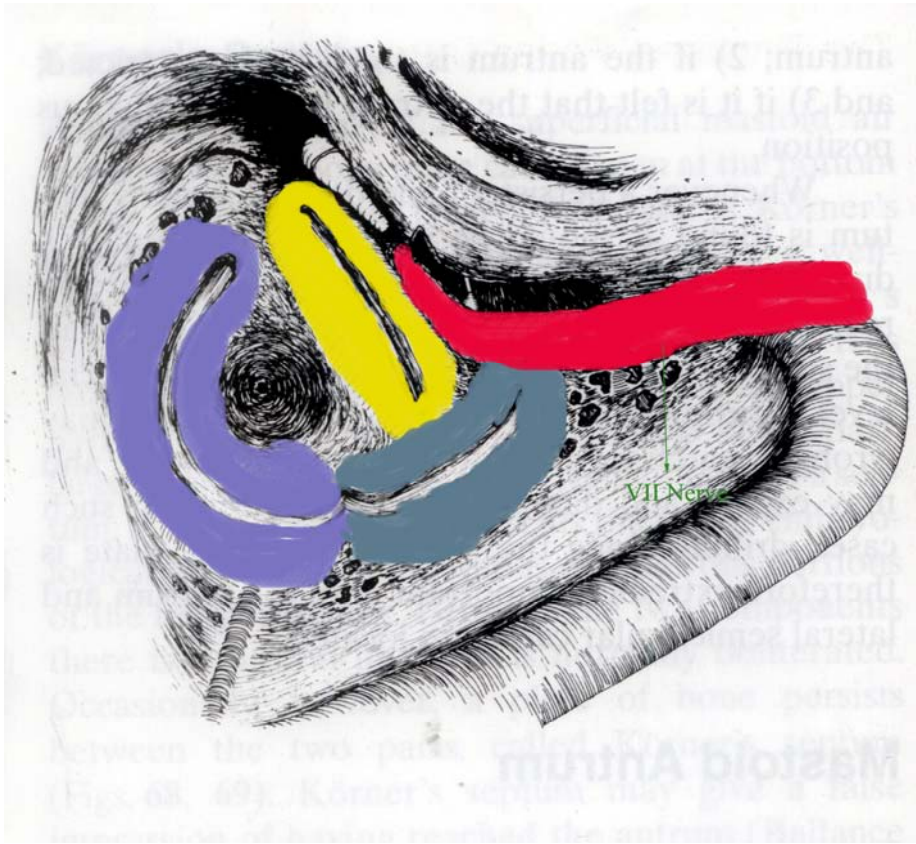


Fig S 18 The interlabyrinthine air cells removed, supralabyrinthine and retro labyrinthine cells opened. Anteriorly the vertical portion of the facial nerve seen.

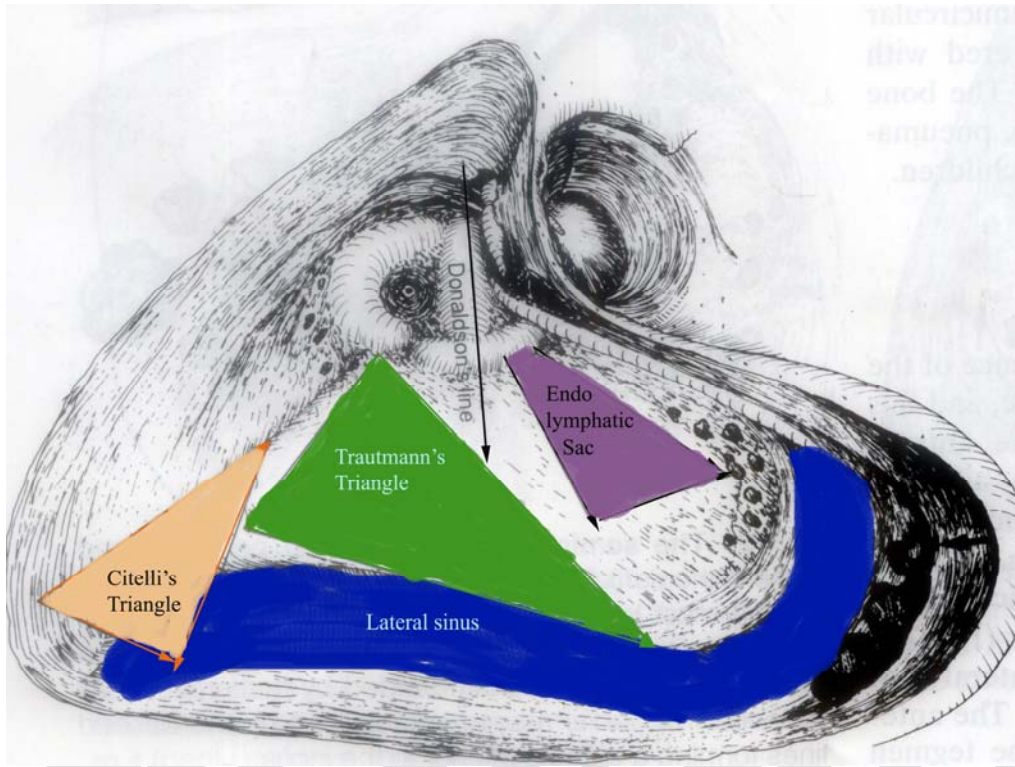


Fig S19 Completed extended mastoidectomy with intact canal wall, entire middle fossa dural plate seen, the sigmoid sinus, the three semicircular canals, and the three triangles clearly demonstrated. Donaldson's line an important surface marking for the position of the endolymphatic sac is also clearly seen

Posterior fossa dural plate:

The posterior fossa dural plate is a large bony plate demarcated superiorly by the superior petrosal sinus, laterally and inferiorly by the sigmoid sinus, and medially by the posterior semicircular canal. This posterior fossa dural plate forms the posterior wall of the antrum and the posterior wall of the petrosal part of the mastoid process. Most of the posterior fossa dura is included in Trautmann's triangle, an imaginary triangle bounded by the tegmen mastoidei, superior petrosal sinus, sigmoid sinus, and the bony labyrinth. Inferior to the Donaldson's line is seen the endolymphatic sac resembling a reflection of posterior fossa dura. **Donaldson's line is an imaginary line drawn perpendicular to the long axis of the lateral canal bisecting the posterior canal up to the sigmoid sinus.**

The tip of the mastoid process in well pneumatized ears usually contains large air cells. At the same depth of the facial nerve there is a ridge known as the digastric ridge. On the external surface of the mastoid process, a corresponding depression

occurs. This is known as the digastric fossa relating to the attachment of the digastric muscle.

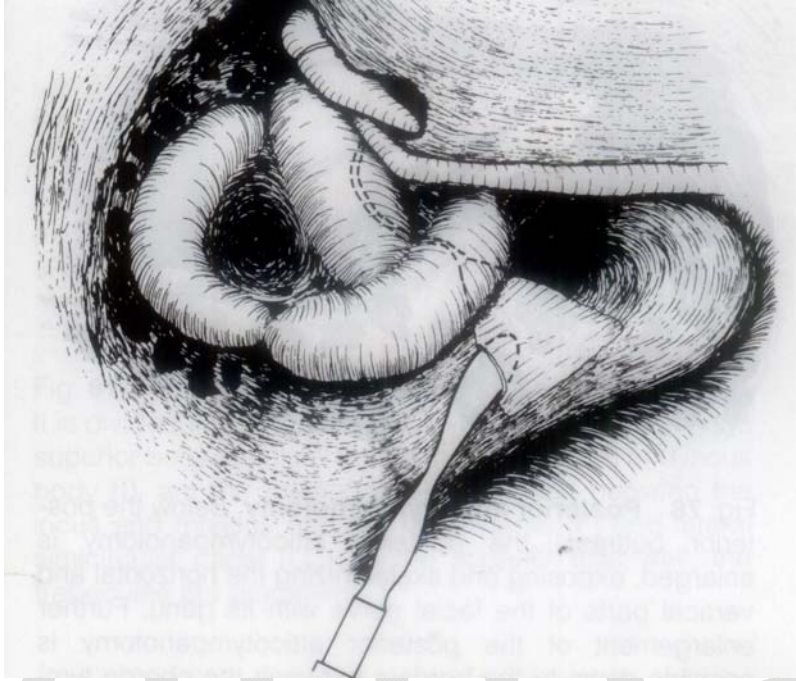


Fig S20 Showing exposure of endolymphatic sac with decompression and opening. The course of the endolymphatic duct, posterior to the posterior semicircular canal toward the vestibule is indicated by dashed lines.

Facial recess:

The facial recess lies immediately lateral to the facial nerve at the external genu of the nerve. It is usually a collection of small air cells continuing from the antrum towards the facial sinus, but there is no communication between these cells and the tympanic cavity. The facial recess is a surgical term. It is a triangle formed by the facial nerve medially, the chorda tympani laterally, and a bony buttress at the incudal fossa superiorly. Middle ear can be accessed by this route and this procedure is known as the posterior tympanotomy.

The primary aim of a posterior tympanotomy is to create a large facial recess during the canal wall up mastoidectomy in order to provide a new route for air flow from the middle ear into the antrum. However the facial recess is postoperatively often relatively closed off by fibrous tissue or adhesions. The other aim is to eradicate disease from the posterior tympanum, especially from the facial sinus and the lateral tympanic sinus, which are located directly lateral to the descending facial canal, it is also useful in facial nerve decompression and in cochlear implantation procedures.



Fig S21 showing facial recess opened – The pyramidal process, incudo stapedial joint, and the round window niche are clearly seen, chorda tympani nerve is shown in dotted lines, the posterior buttress i.e. arrow is left intact – Posterior buttress is a bony bridge between the ear canal and the bone covering the lateral semicircular canal.

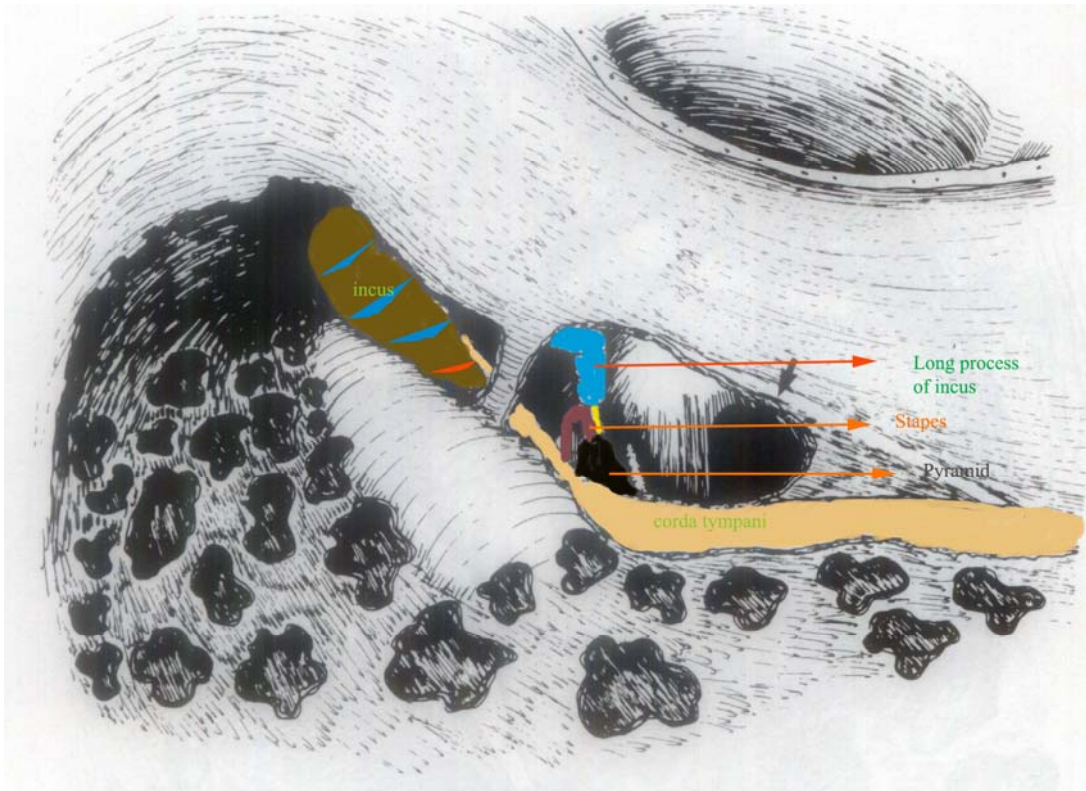


Fig S22 showing posterior atticotomy showing the chorda tympani nerve, lateral semicircular canal, incus. Through the posterior tympanotomy middle ear is visualized. The posterior buttress is left intact.

The attic:

The attic or epitympanum is an important structure. It provides communication between the antrum and the rest of the tympanic cavity. Surgically it is difficult to reach, especially when a low dura is encountered, as is often the case in cholesteatoma surgery. The high frequency of postoperative attic retraction and recurrent cholesteatoma indicates that ventilation of the attic is difficult to maintain after surgery.

The superior border of the attic is the tegmen tympani, which is a thin bony wall, at times transparent or even dehiscant. There are often bony trabeculae present that resemble air cells. These cells connect with periantral cells posteriorly and perilabyrinthine cells medially, as well as with the cells of the meatal wall laterally.

The attic is divided into medial and lateral parts. The border between the two parts is formed by the head of the malleus and the body of the incus, the medial attic

being larger. The distance between the prominence of the lateral canal and the body of incus is 1.7 mm, and slightly less at the level of the malleus head. The medial attic communicates with the mesotympanum through an opening - the isthmus tympani – bounded by the lateral semicircular canal and the prominence of facial nerve medially and the ossicles malleus and incus laterally. The isthmus tympani is a narrow elongated space, and is divided by the long process of incus into an anterior isthmus, with the tendon of the tensor tympani as its anterior border, and the posterior isthmus, bounded by the posterior wall of cavum tympani, the pyramidal eminence, and the buttress at the fossa incudis. The terms isthmus tympani posticus and isthmus tympani anticus are also used. Through the tympanic isthmus, and especially through the posterior isthmus, sinus cholesteatomas can spread to the attic. The tympanic isthmus is extremely important for attic ventilation.

The lateral attic is located between the outer attic wall laterally (the scutum) and the malleus head and incus body medially. Because of the outward projection of the ossicles, the lateral attic is smaller than the medial one. The outer attic wall (scutum) runs obliquely from the tegmen tympani to the upper edge of bony annulus, making the lateral attic even smaller. The communication between the lateral attic and the mesotympanum varies considerably. At the level of the malleus and the anterior to the malleus, it is virtually non existent. At the level of incus, the communication varies from a small fissure to a small, oval shaped cavity. The lower border of the communication is the chorda tympani, and the upper border is the annulus and the lateral malleolar ligament. The connection is often closed by various small mucosal folds or adhesions.

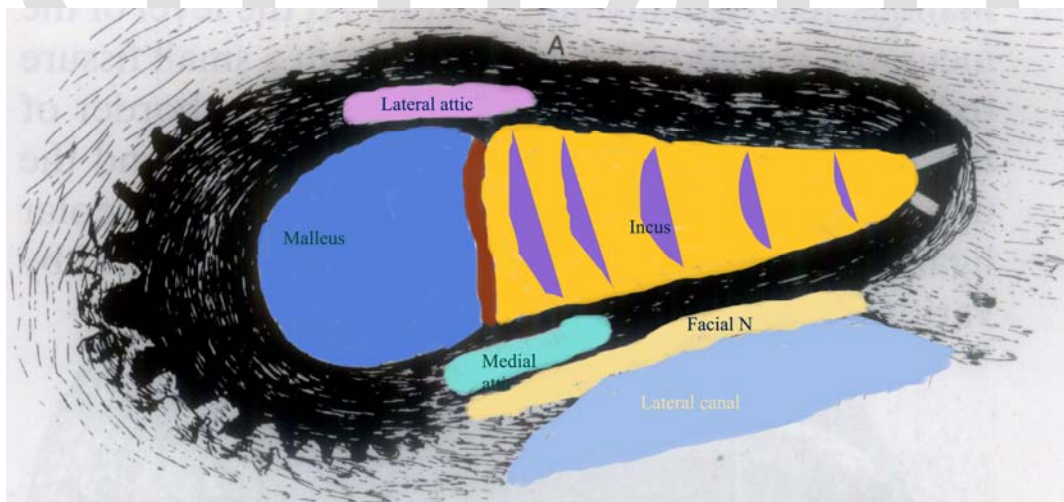


Fig S 23 Attic seen from above- Divided into medial and lateral attic

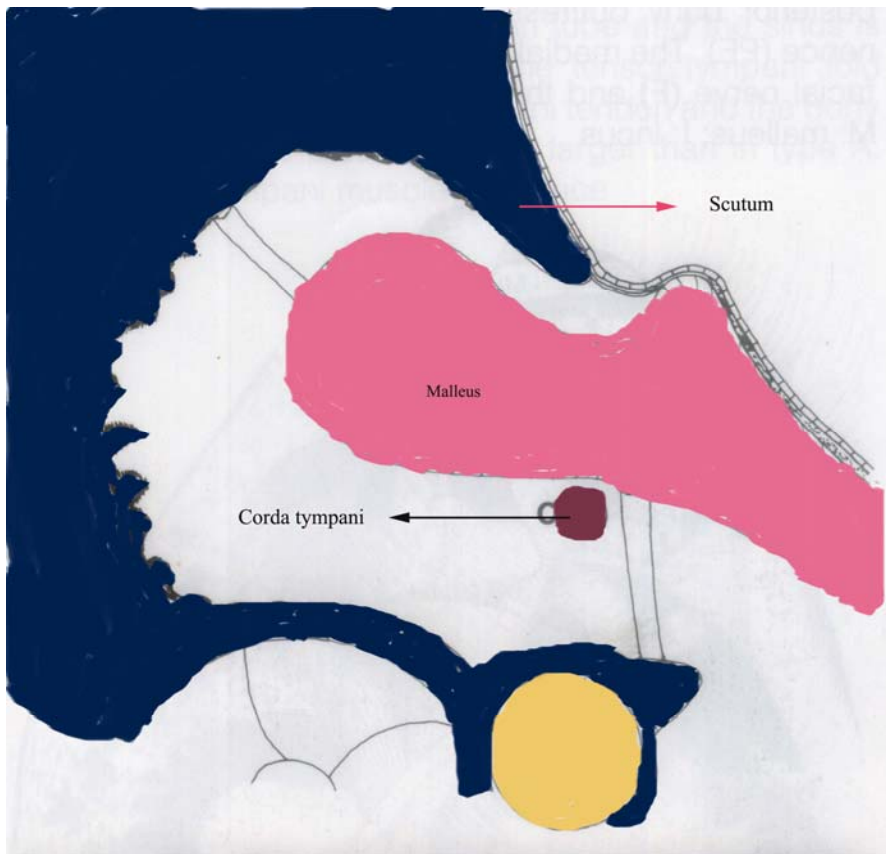


Fig S24 Attic seen from behind at the level of the malleus showing the superior malleolar liament superiorly, medial malleolar ligament medially. The lateral attic is the space between the lateral attic wall and the bony annulus and the malleolar head. Medial attic is between the malleus and the lateral canal and is larger

The anterior wall of the attic is narrow, and the malleus head is in very close proximity to the bony spicules of the tegmen tympani. The fact that this is a common site for a bony bridge to form between the spicules and the anterior surface of the malleus head is understandable and may be caused by simple mechanical irritation in that area or due to inflammation. But the most common cause of bony fixation is previous surgery in that area. It is hence mandatory to avoid surgical disturbance to attic in simple mastoidectomy. If surgery in the attic region cannot be avoided, it is best to remove all bony spicules and to create a large space between the attic wall and the ossicles, in order to avoid post op bony fixation.

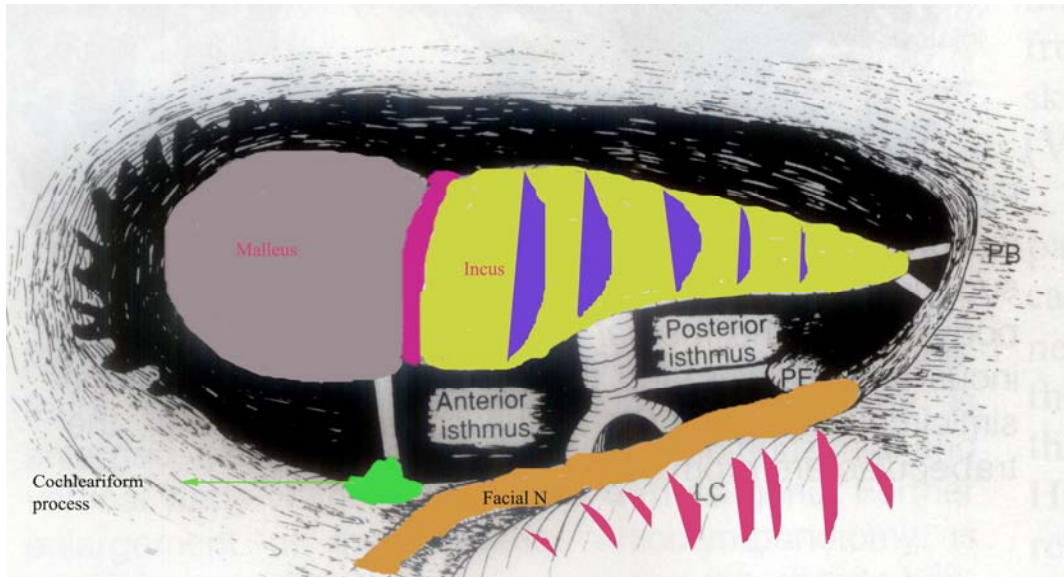


Fig S 25 Lateral canal is seen (LC) anterior tympanic isthmus lies between the tendon of tensor tympani muscle with the cochleariform process, the long process of incus and the stapedial arch. The posterior tympanic isthmus lies between the long process of incus, the posterior bony buttress (PB), and the pyramidal eminence (PE), the medial borders of the two isthmi are the facial nerve and the lateral canal (LC).

The epitympanic sinus:

Is a separate cavity of varying shape and size situated anterior to the attic, the two cavities being separated by a bony crest coming from the tegmen tympani. The crest is called the anterior attic plate or the cog. The superior wall of the epitympanic sinus is the tegmen tympani, and in some cases the anterior wall also because of the angulation of the tegmen towards the eustachean tube. The medial wall of the sinus is the bone covering the facial nerve at the geniculate ganglion. The lateral wall is formed by the tympanic ring. The inferior border is either the tensor tympani fold or the prominence of the canal of the tensor tympani muscle.

The shape of the epitympanic sinus varies. It can be divided into three main types.

Type A: is a relatively deep sinus anterior to the bony prominence (cog). The sinus is entirely enclosed by bone, except for a narrow opening below the cog. The tensor tympani fold is attached to a relatively thick bony plate anteriorly separating the sinus from the eustachean tube. The tubal recess, also known as supratubal recess, is poorly developed. Found in 38% of cases.

Type B: is found in 40% of cases. The bony plate around the tube is poorly developed, and is connected with a long tensor tympani fold. The tubal recess is larger, but the epitympanic sinus is smaller.

Type C: There are no well defined anterior and inferior boundaries. The sinus slopes down to the eustachean tube and creates a large tubal recess. Seen in 18% of cases.

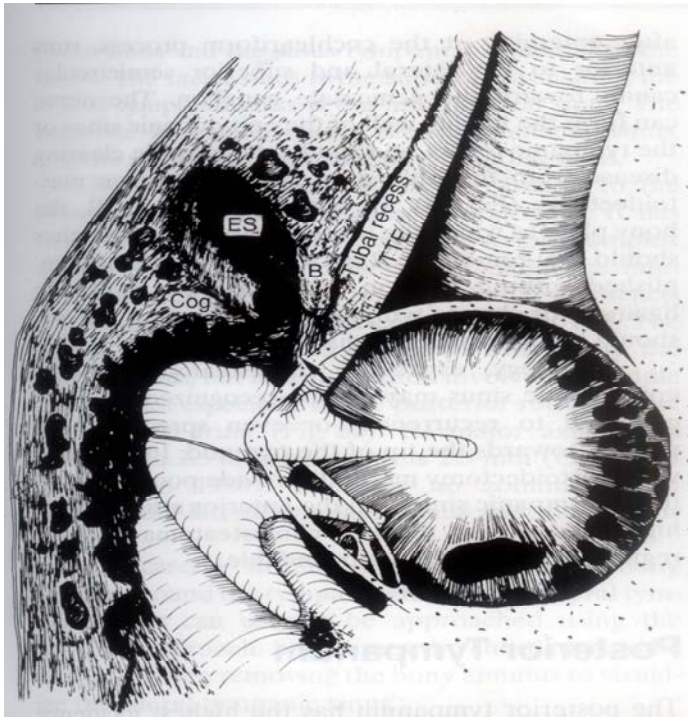


Fig S26 Type A epitympanic sinus. The sinus (ES) is deep and totally surrounded by bone except for a narrow opening below the cog. The bony plate (B) separating the eustachean tube from the epitympanic sinus is long and prominent; the tensor tympani fold (arrow) is short. The tubal recess is poorly developed or not present.

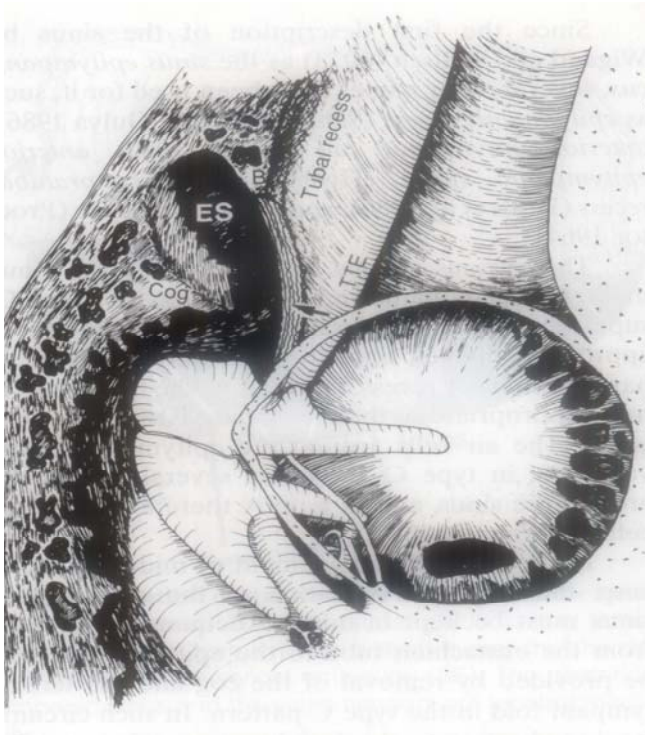


Fig S27 Type B epitympanic sinus. The bony plate (B) between the eustachean tube and the sinus is poorly developed and short. The tensor tympani fold (arrow) between the tensor tympani tendon and the bony plate is long. The tubal recess is larger than in type A. TTE IS Tensor tympani eminence.

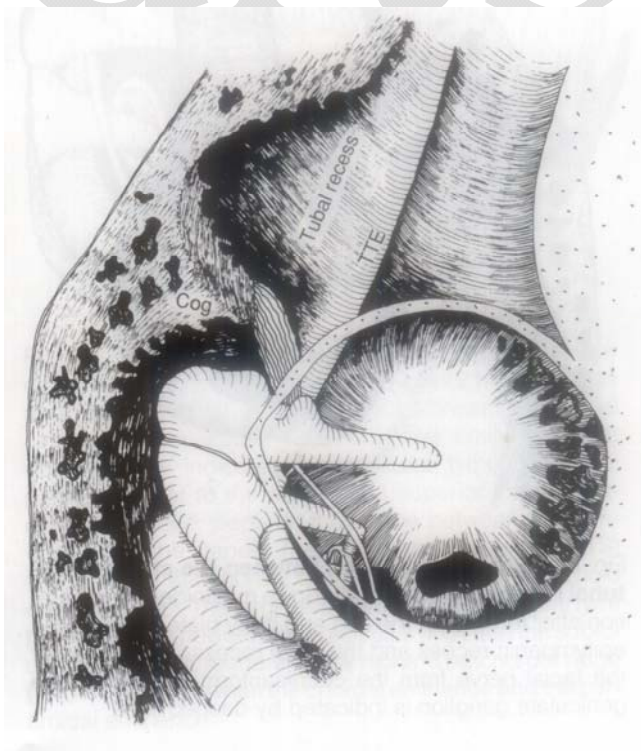


Fig S28 Type C epitympanic sinus

In the surgical management of middle ear disease, the structural variation of the epitympanic sinus must be kept in mind. Adequate ventilation from the eustachean tube to the epitympanum can be provided by the removal of the cog and the tensor tympani fold in the type c pattern. In such circumstances, damage to the facial nerve and especially the geniculate ganglion is possible. The facial nerve on emerging at the cochleariform process runs anterior to the lateral and superior semicircular canals toward the geniculate ganglion. The nerve can form the medial wall of the epitympanic sinus or tympanic recess, and can be damaged in clearing disease from the attic in a canal wall down mastoidectomy. In both types A and B, the bony plate to which the tensor tympani fold attaches should be removed. Removal should be accomplished without division of the anterior malleolar fold or chorda tympani. Drilling of the cog should be performed medial to the chorda.

Cholesteatoma in the epitympanic sinus may not be recognized, and this can lead to recurrences or even spread of the process towards the tip of the pyramid. Intact canal wall procedures provide poor access to the epitympanic sinus and the anterior attic.

Posterior Tympanum:

The posterior tympanum has the highest incidence of middle ear pathology, especially retractions and cholesteatomas.

The anatomy of the posterior tympanum can be described a) through the ear canal, or b) through the facial recess.

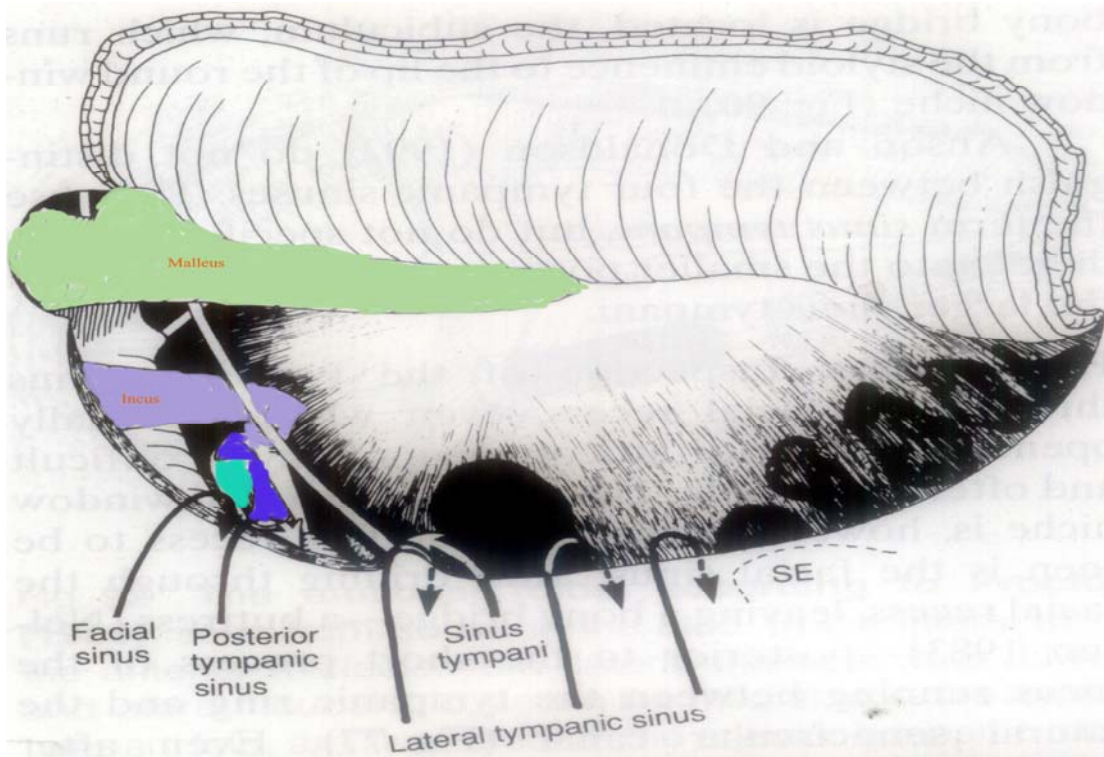
Posterior tympanum through the ear canal:

The posterior tympanum can be visualized through the ear canal using endaural approach. It can be visualized when the bony annulus is drilled away and the patient's head is tilted backward. In the posterior tympanum there are four sinuses which become visible only when the annulus is partially drilled out and the head tilted backward. Two are located suprapyramidally, i.e. superior to the pyramidal eminence – the facial sinus and the posterior tympanic sinus. Two are infra pyramidal – the lateral tympanic sinus and the sinus tympani.

In relation to the facial nerve in the posterior tympanum, two sinuses are lateral and external to the facial nerve – the facial sinus and the lateral tympanic sinus, whereas the posterior tympanic sinus and the sinus tympani are medial to the nerve. The facial sinus is thus a superolateral sinus; the lateral tympanic sinus is the inferolateral sinus. The posterior tympanic sinus is the superomedial sinus, and the sinus tympani is the inferomedial sinus.

The lateral tympanic sinus: is the most lateral sinus. It lies between the three eminences of the styloid complex. The lateral tympanic sinus is hidden just medial to the bony annulus, but is often involved in middle ear diseases especially in the posterior retraction of the atrophic drum. There is no communication between the lateral tympanic sinus and the attic or antrum.

By carefully drilling the bony posterior meatal wall and annulus around the tympanic chorda, the lateral tympanic sinus can be accessed.



S29 Sinuses of posterior tympanum – SE styloid eminence

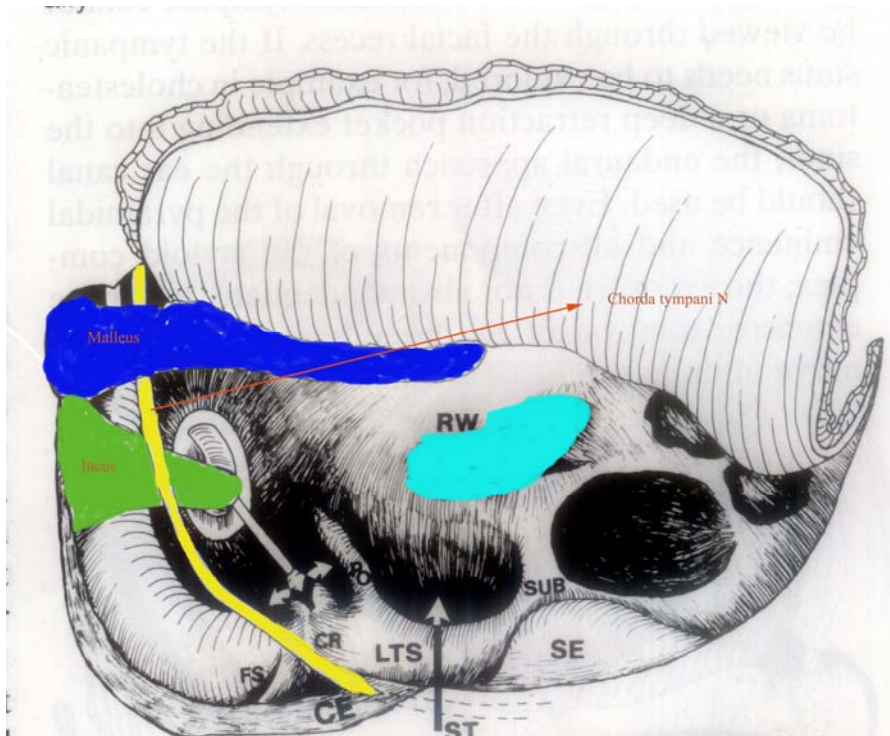


Fig S30 Postero superior bony annulus drilled completely – FS Facial sinus, RW round window, PE pyramidal eminence, PO ponticulus, CE chordal eminence, ST sinus tympani, SE styloid eminence, SUB subiculum, CR chordal ridge.

The facial sinus – is also a lateral sinus. It is situated at the genu of the facial nerve canal, medial to the bony annulus and chordal eminence, but superior to the chordal ridge and the pyramidal eminence. There is no connection between the facial sinus and the air cells of the attic or mastoid process. When approaching from behind through the facial recess, the facial sinus is entered directly. Failure to clear this area is the most common cause of residual cholesteatoma.

The posterior tympanic sinus is a medial sinus. It lies medial to the facial nerve and the pyramidal eminence, but superior to the ponticulus – a bridge located between the posterior tympanic wall and the promontory. In fact it is the ponticulus that divides the tympanic sinus into the smaller posterior tympanic sinus and the larger inferior sinus, called the sinus tympani.

The sinus tympani is the largest sinus. It is a medial and infrapyramidal sinus. It lies deep to the descending part of the facial nerve, inferior to the ponticulus and the pyramidal eminence. At the inferior border of the tympanic sinus, a small bony bridge is located, the subiculum, which runs from the styloid eminence to the lip of the round window niche.

Facial recess:

Inspection of the tympanic sinus through the facial recess, even when maximally opened in posterior atticotomy, is difficult. The view to the round window is excellent. The first recess to be seen is the facial sinus, after drilling through the facial recess, leaving a bony ridge posterior to the short process of incus running

between the tympanic ring and the lateral canal. If the tympanic sinus needs to be explored then an endaural approach is preferable.

Tympanic diaphragm:

Is a term first coined by Proctor in 1964. It defines the obstacles within the tympanic isthmus and the attic. These obstacles are the tympanic folds and ligaments running between the surrounding bony structures and the incus body and malleus head. It is a pretty crowded space. The tympanic diaphragm divides the attic from the mesotympanum. The tympanic diaphragm is a common site for impairment of ventilation to the antrum. Wullstein goes to the extent of describing this region as the second bottle neck of air flow, the first being the eustachean tube.

Mucosal folds:

These folds divide the attic space into various compartments. They are located both in the lateral and medial attic.

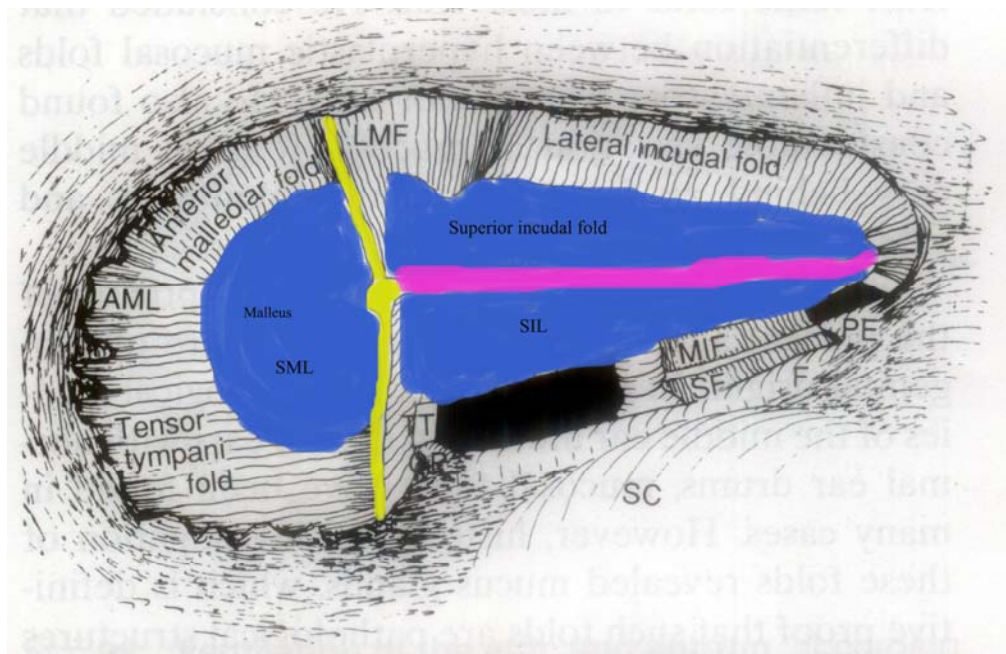


Fig S31 The mucosal folds forming the tympanic diaphragm LMF lateral malleolar fold, SIL superior incudal ligament, TT Tendon of the tensor tympani, SML superior malleolar ligament, F facial nerve, AML anterior malleolar ligament.

The lateral incudal fold connects the lateral attic wall and the body and the body of the incus. It extends posteriorly to the posterior incudal ligament.

The anterior malleolar fold of von Troltsch is located between the anterior surface of the malleus head, and the antero lateral bony wall of the attic, and the anterior malleolar ligament.

The superior malleolar fold extends between the superior surface of the malleus head and the superior attic wall, and in the same plane as the superior malleolar ligament.

The superior incudal fold extends, like the superior incudal ligament, between the superior aspect of the incus body and the superior attic wall.

The medial incudal fold is located between the long process of the incus and the tendon of the stapedial muscle, as far as the pyramidal eminence.

The lateral malleolar fold goes from the neck of the malleus up to the scutum forming the superior border of Prussak's space.

The interossicular fold extends between the malleus handle and the long process of incus.

The anterior malleolar ligament extends from the long process of the malleus toward the anterior attic wall.

The tensor tympani fold occupies the window between the tensor tympani tendon, the anterior bony plate of the attic wall, the tensor tympani eminence, and the anterior malleolar ligament.

The folds most commonly seen are 1. The tensor tympani fold, 2. The lateral incudal fold, 3. The medial incudal fold between the crura of the stapes and the incus 4. The lateral malleolar fold, 5. the stapedial fold between the posterior crus of the stapes and the posterior tympanic wall, following the stapedial tendon and the pyramidal eminence and 6. The obturator fold between the stapedial crura. The mucosal folds are very thin and carry blood vessels to the ossicles.

According to Proctor ventilation of the attic never goes through the anterior attic, but only through the tympanic isthmus, i.e. posterior to the tensor tympani tendon. The anterior attic space, according to proctor is blocked by the tensor tympani mucosal fold.

Recent studies show that these folds may be sequelae of previous infections or inflammation of the middle ear. Hence they can be considered as post inflammatory adhesions. Histology of these folds reveals mucosal glands which is a definite proof of inflammatory origin.

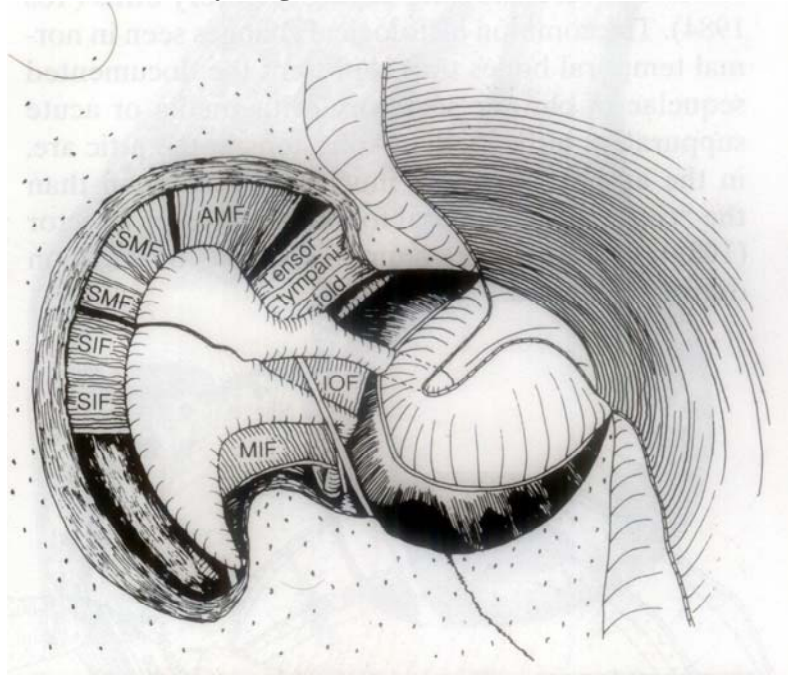


Fig S 32 showing mucosal folds of attic

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